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CONTENTS

page

LIE, ULF: Quantities of zooplankton and propagation of *Calanus Finmachicus* at permanent stations on the Norwegian coast and at Spitsbergen, 1959—1962 5

MYRBERGET, SVEIN: Distribution of mackerel eggs and larvae in the Skagerrak, 1957—1959 20

ØSTVEDT, OLE J.: The migration of Norwegian herring to Icelandic waters and the enviromental conditions in May—June, 1961—1964 29

DRAGESUND, OLAV and OLSEN, STEINAR: On the possibility of estimating year-class strength by measuring echo-abundance of 0-group fish 48

OLSEN, STEINAR: Abundance estimates of Barents Sea capelin 76

QUANTITIES OF ZOOPLANKTON AND PROPAGATION OF *CALANUS FINMARCHICUS* AT PERMANENT STATIONS ON THE NORWEGIAN COAST AND AT SPITSBERGEN, 1959—1962

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INTRODUCTION

Zooplankton has been collected at permanent oceanographic stations along the Norwegian coast since 1948. The purpose of these long-range plankton studies is mainly to follow the annual and seasonal changes in the food conditions for plankton-feeding fishes. Also, the samples provide material for an analysis of the abundance of eggs and larvae of commercially important fishes in Norwegian coastal waters.

The permanent stations were originally Sognesjøen, Ona, Skrova and Eggum (Fig. 1). Skarsvåg and Kongsfjorden at Spitsbergen were added in 1955 and 1957; the sampling at Ona was abandoned in 1957. Since 1948, zooplankton has also been collected at the weather ship "M" at 66°N, 02°E in the Norwegian Sea.

The hydrographical conditions at the various stations are representative of the conditions in the Norvegian coastal water at the corresponding latitudes. Hydrographic data from the permanent stations have been collected simultaneously with the zooplankton and processed at the hydrography section of the Institute of Marine Research, Directorate of Fisheries.

The zooplankton was completely identified and counted from 1948—1951 (Wiborg 1954), but has since been less thoroughly analyzed. The emphasis has been on measuring displacement volumes, the dominating species of zooplankton have been noted, and fish-eggs and larvae have been identified and counted. Since 1959 the percent composition of development-stages of *Calanus finmarchicus* has also been estimated.

Wiborg (1954) described the annual and seasonal changes in the quantities of zooplankton at the permanent stations from 1948 to 1951.

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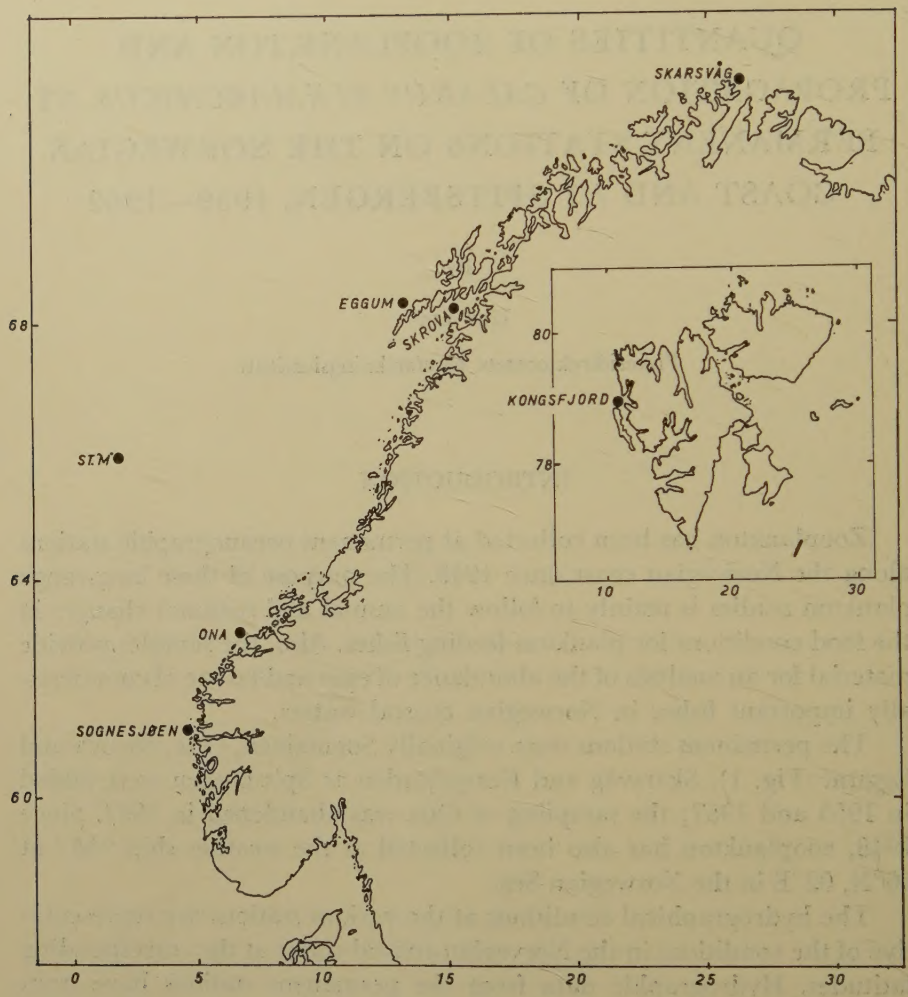

Fig. 1. Permanent zooplankton stations (from WIBORG 1958).

He also discussed the composition of the zooplankton and various aspects of the biology of the important species. The quantity of zooplankton at the permanent oceanographic stations until 1958 was reported by WIBORG (1958 and 1960).

The current paper reports on the zooplankton quantities and the propagation of *Calanus finmarchicus* at Sognesjøen, Skrova, Eggum, Skarsvåg, and Kongsfjorden during the period 1959—1962.

MATERIAL AND METHODS

The present report is based on 734 samples from five stations. The material from Skrova is by far the most complete, averaging more than eight samples per month, while the average for the other four stations is less than four.

The majority of samples were collected with Nansen-nets with mouth diameter 70 cm and mesh size 0.2 mm. In 1961 and 1962 this gear was replaced by Juday-nets with 40 cm diameter in the upper ring, and the same mesh size as the Nansen-nets. When calculating the volume of zooplankton per square meter of surface, it has been assumed that the catch per unit area was the same for the Nansen-nets and for the Juday-nets.

Two samples were taken per station per sampling date: one sample from the 50—0 m layer, the second from the bottom to the surface. All the samples were preserved in 5—10 percent formalin.

The volume of the zooplankton was measured by the displacement method (Wiborg 1954). Presence of large quantities of phytoplankton may reduce the accuracy of the measurements considerably by clogging the sieves, but by washing the samples thoroughly before measuring volume, most of the phytoplankton can be removed.

The volumes of zooplankton per square meter of surface have been calculated and the monthly means of these values are presented in Figs. 2—6.

The propagation of *Calanus finmarchicus* has been studied by determining percentage distribution of the first 100 *Calanus* copepodites counted when examining the sample under a dissecting microscope. This method probably does not meet the requirements for random sampling; therefore, the data have not been used for any statistical evaluations. The bias introduced by the method of subsampling does not permit much emphasis on single observations of stage distribution, but demands consideration of trends in large numbers of samples.

The percentage developmental stage distribution as monthly means averaged for the years 1959—1962 at the various stations is presented in Figures 7—10.

VOLUMES OF ZOOPLANKTON AT THE PERMANENT STATIONS, 1959—62

Sognesjøen (Fig. 2)

Very few samples are available from this station, a circumstance which makes the study of seasonal changes in the biomass uncertain. The spring increase seemed to start in April, the maximum was reached

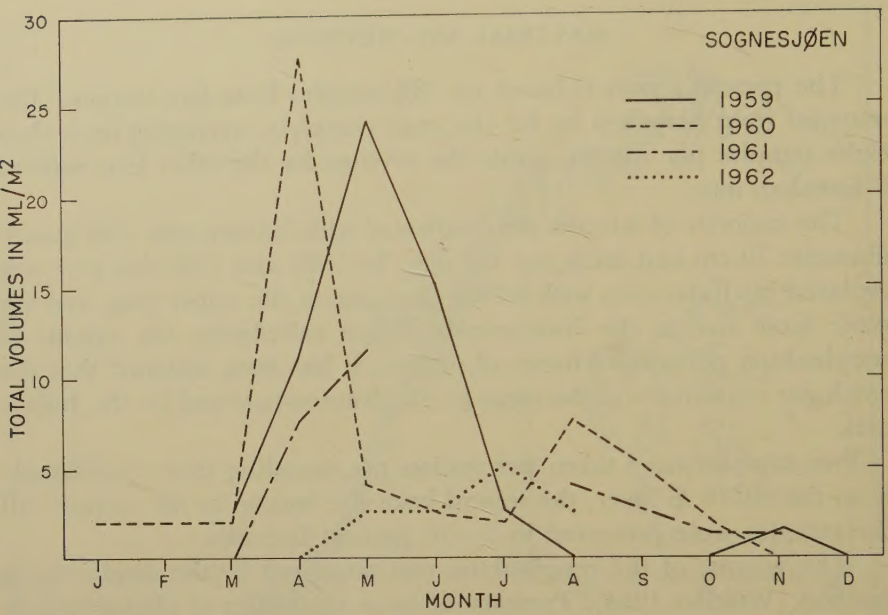

Fig. 2. Monthly mean total volumes in ml/m² of zooplankton at Sognesjøen, 1959—1962.

in April or May. A second, less pronounced peak could be detected in July—August.

Wiborg (1954, 1958, 1960) found the same general trend in the seasonal variations in biomass of zooplankton, and his data reveal considerable variations from one year to another. However, Wiborg also had relatively few observations from this station, which may account in part for the variations.

Skrova. (*Fig. 3*)

The quantities of zooplankton in the 50—0 m samples were very poor during the first three months of all the years investigated. The spring increase was observed from the middle of April, and for all years two significant peaks were found; one in May and one in June. A third, less pronounced peak occurred in September-October.

Fairly high densities of zooplankton were observed all year round in the 300—0 m samples. 3). The minimum was found in March, and the same three peaks occurred as in the 50—0 m samples. The two separate peaks in May and June are not revealed by the monthly mean values per m².

From February on, an increasing proportion of the zooplankton was found in the upper 50 m layer, and during April, May, and June, more than 50% of the total standing stock occurred in this layer. The relative

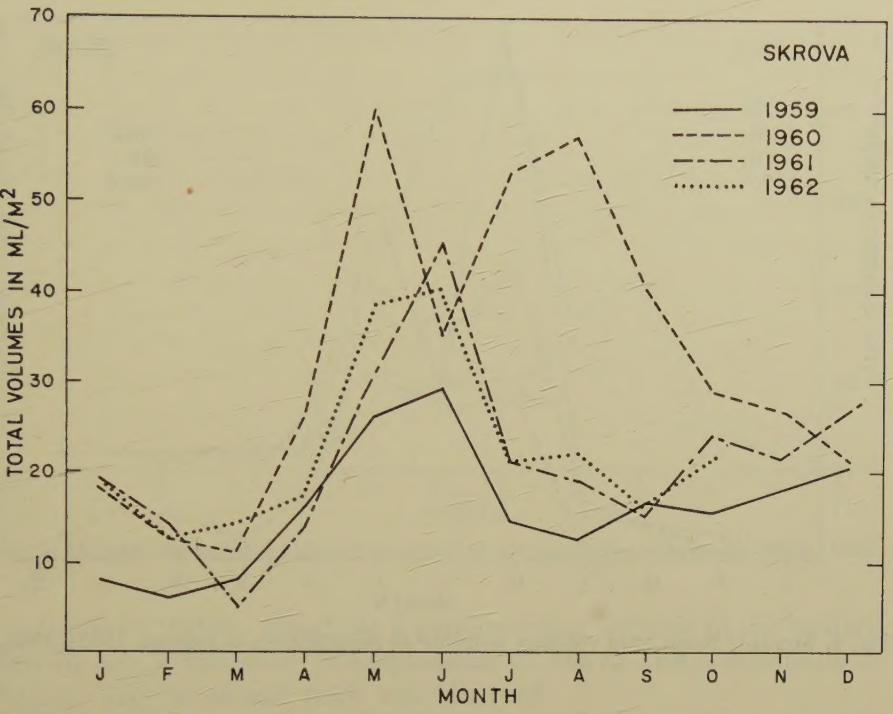

Fig. 3. Monthly mean total volumes in ml/m² of zooplankton at Skrova, 1959—1962.

density of zooplankton in the 50—0 m samples was also prominent during the peaks in September—October 1959 and 1961, but not in 1960. From October the amount of zooplankton in the upper 50 m layer decreased rapidly, and during December and January less than 5% of the total biomass was found in this layer.

The variations in zooplankton volumes per square meter of surface from 1959 to 1962 (Fig. 3) correspond largely to those observed by Wiborg (1954, 1958, 1960). He demonstrated that considerable changes may occur at this station from one year to another as regards time for the peaks and the mean annual richness of zooplankton.

Eggum. (Fig. 3)

The spring increase in the 50—0 m samples at this station was always found in April, reaching a maximum of volume in May. In 1960, no other peaks were found, whereas a second peak occurred in August 1961 and June 1962.

The 200—0 m samples from 1960 revealed peaks in May and early July, and a slight increase in October. (Fig. 4). The same pattern was found in 1961, but as no samples were collected later than September,

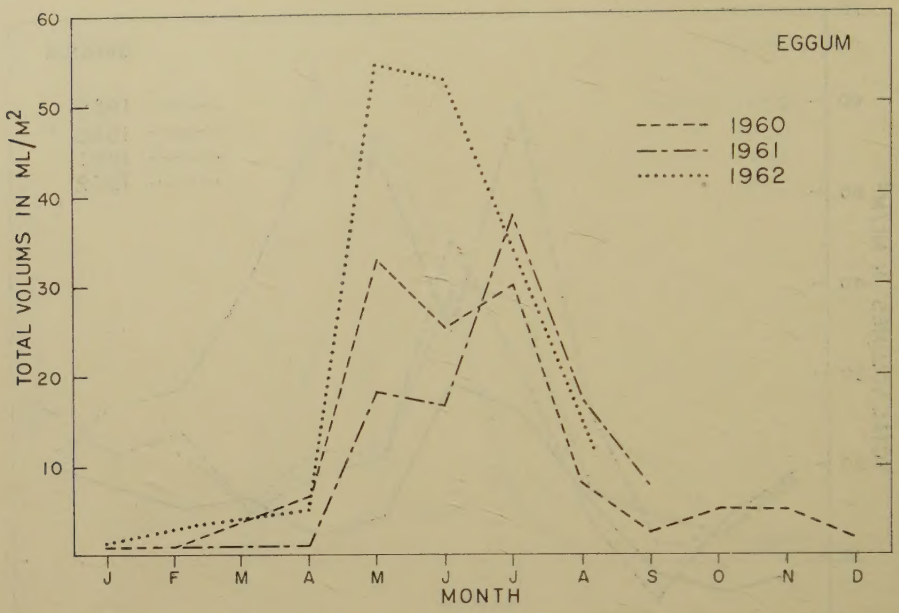

Fig. 4. Monthly mean total volumes in ml/m² of zooplankton at Eggum, 1960—1962.

an eventual third peak could not be detected. Also in 1962 the spring maximum in the 200—0 m samples was found in May, and a second peak seemed to occur at the end of June.

The zooplankton density in the winter season from September to April was extremely poor and no significant difference between the 50—0 and the 200—0 m samples was found. During the summer season, however, the volumes of the 200—0 m layer were considerably higher than the volumes of the 50—0 m samples.

Wiborg (1954, 1958) found largely the same pattern, and he emphasized the extensive variations from one year to another.

Skarsvåg. (Fig. 4)

The spring increase in the 50—0 m samples was observed from April—May. The maximum was as a rule found in July, but in 1962 it occurred as early as the middle of June. A small second peak could be detected in August—September 1960 and 1961. The volumes of the 260—0 m samples followed the same pattern.

The main part of the zooplankton seemed to be concentrated in the upper 50 m during the first half of the year, while the relative density of zooplankton in this layer decreases after the spring maximum when the plankton descends for overwintering in the deeper water layers.

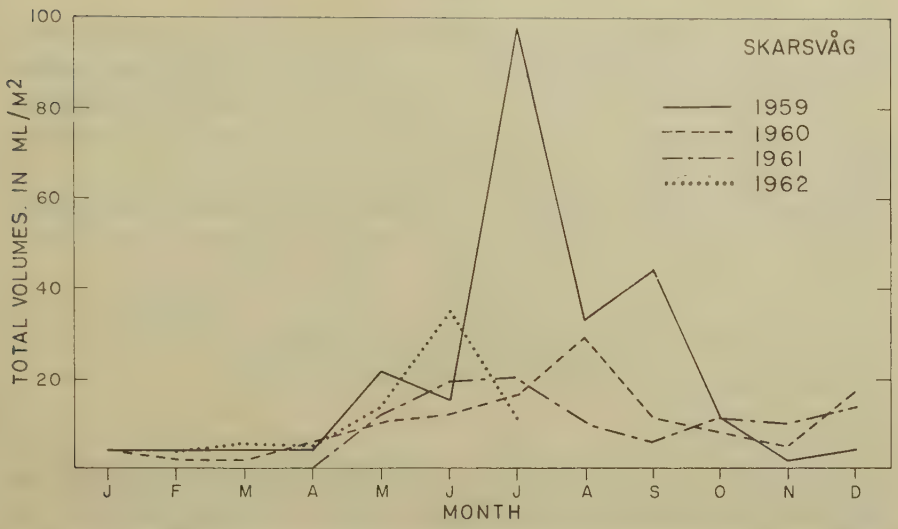

Fig. 5. Monthly mean total volumes in ml/m² of zooplankton at Skarsvåg, 1959—1962.

Jashnov (1939a) found, at a corresponding latitude in the western Barents Sea, a minimum of zooplankton in March and a maximum in August, and no second peak was observed.

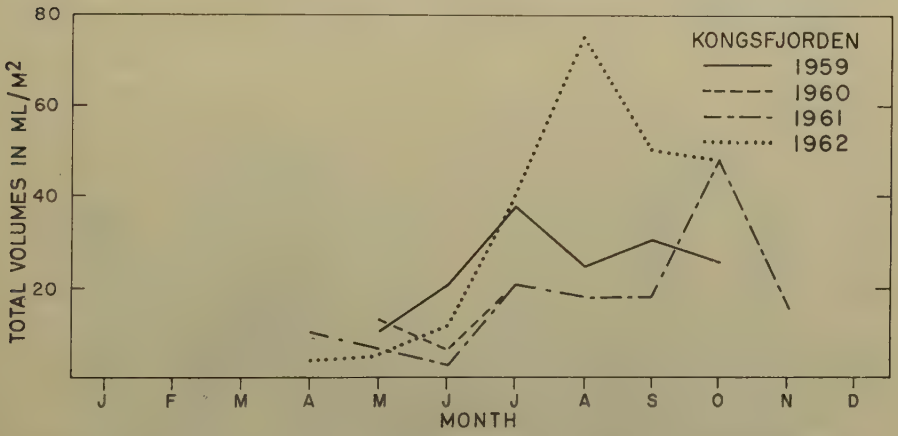

Fig. 6. Monthly mean total volumes in ml/m² of zooplankton at Kongsfjorden, 1959—1962.

Kongsfjorden (Fig. 6)

The scarcity of samples from this station prevents a complete discus- of the seasonal variations in the biomass of zooplankton. The spring increase started in June, but no general trend in the occurrence of the

maximum was revealed. However, high amounts of zooplankton were found from July, until the sampling was ended in October—November.

Up until June the main part of the zooplankton seemed to be concentrated in the upper 50 m, but from July onwards, the relative importance of the biomass of this water layer decreased steadily.

According to WIBORG (1960) the highest volumes of zooplankton were found during the last half of the year, both in 1957 and 1958.

PROPAGATIONS OF *CALANUS FINMARCHICUS* AT THE PERMANENT STATIONS, 1959—1962

Sognesjøen (Fig. 7)

The complete picture of the propagation of *Calanus finmarchicus* at Sognesjøen is rather uncertain due to the scarcity of samples. However, during all the years investigated there was a maximum of females at the end of February or the beginning of March, followed by high percentages of young copepodites during March. The main spawning evidently must have taken place in the first half of March. The percentage distribution of females, males, and young copepodities during the rest of the year indicates, as shown in Fig. 7, that spawnings also took place in early June and August.

High percentages of the copepodite stage V during summer and fall in the 200—0 m samples, indicate that only part of the spring generation

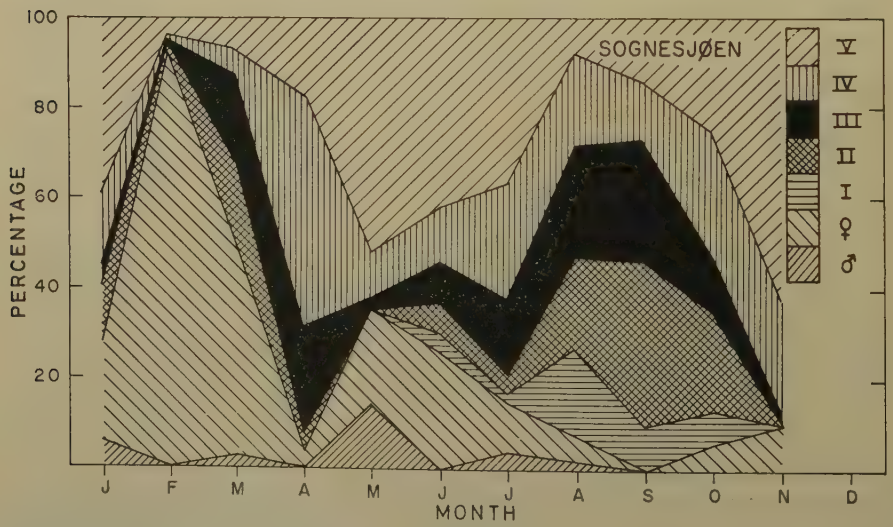

Fig. 7. Variations in the percentage distribution of males, females and copepodite stages I—V of *Calanus finmarchicus* at Sognesjøen. Monthly mean figures 1959—1962.

reaches maturity and spawns the same year, while the main part of the stock stays in the deeper waters as copepodite stages IV and V until next spring.

Three spawnings of *Calanus finmacrhicus* in coastal waters of south-western Norway have been recorded by several authors (Ruud 1929, Runnström 1932, Gundersen 1953, and Wiborg 1954), and Wiborg could even demonstrate that a fourth spawning occurred in 1949. Wiborg calls the spawning in March the "main spawning" and the later spawnings "minor spawnings", by which he probably implied that, as stated above, only a part of the spring generation takes part in the two latest spawnings.

However, as Wiborg based his terms "main" and "minor" spawnings on percentages, they do not reveal which of the spawnings actually was the most important because this will depend on the total number of animals present. In spring during the first spawning the stock is very small and, even if 100 percent of the population reaches maturity and spawns, the number of *Calanus* produced may still be smaller than the number produced by a lower percentage of adults in the autumn when the *Calanus* stock is larger. The percentage distribution of the development-stages does not therefore necessarily reveal the importance of the spawning. However, the spring spawning at all stations was followed by a sharp increase in the zooplankton biomass (Figures 2—6) which indicates that the first spawning really is the main spawning in the sense of production of new animals.

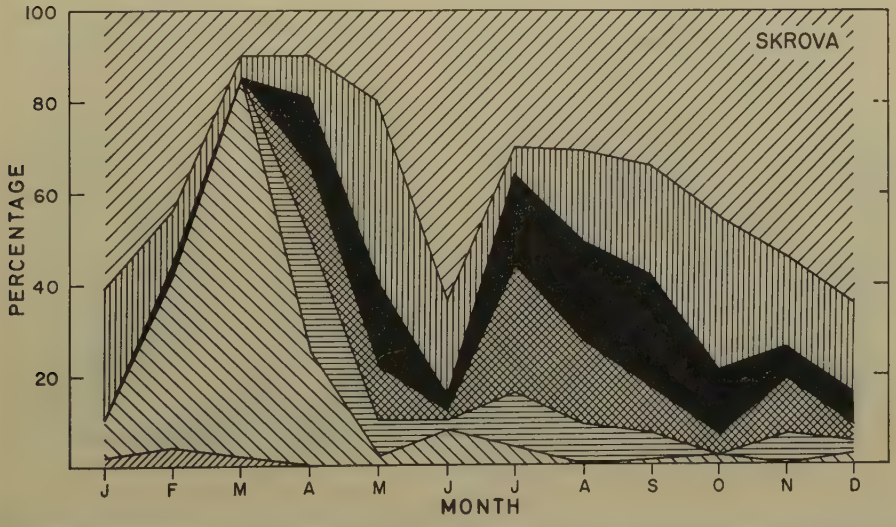

Fig. 8. Variations in the percentage distribution of males, females and copepodite stages I—V of *Calanus finmarchicus* at Skrova. Monthly mean figures 1959—1962. Symbols as in Fig. 7.

Skrova (Fig. 8)

During all the years investigated the maximum of females was found in the middle of March, and the corresponding copepodite stages I and II occurred from the end of March with a maximum in the middle of April, which indicates that the main spawning took place in the last half of March. A second peak of females occurred in June—July and high percentages of copepodite stages I and II were present from the middle of July, from which one may conclude that a second spawning of *Calanus finmarchicus* occurred in the first half of July. Fig. 8 indicates that some spawning may also have occurred in October.

High percentages of the copepodite stage V in the 300—0 m samples indicate that only a part of the spring generation spawned the same summer.

These results are in good agreement with Wiborg (1954), who stated that *Calanus finmarchicus* at Skrova spawned in April-May and in July—August. He also suggested that a minor spawning must have occurred in June. This suggestion was, however, built only on the occurrence of a small number of nauplii, and could not be followed through the copepodite stages.

Eggum (Fig. 9)

No samples from March 1961 and 1962 are available, but the occurrence of the copepodite stages I and II in April both years indicates that

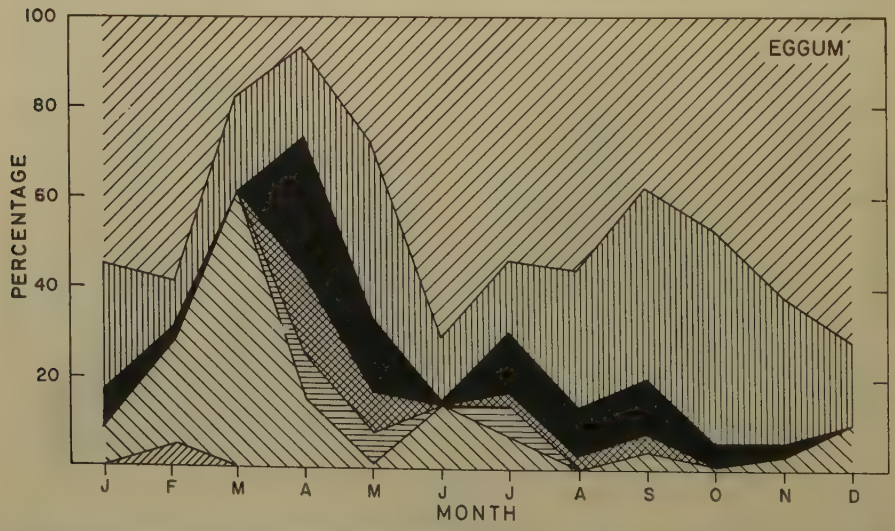

Fig. 9. Variations in the percentage distribution of males, females and copepodite stages I—V of *Calanus finmarchicus* at Eggum. Monthly mean figures 1960—1962. Symbols as in Fig. 7.

the maximum of females must have been in March, which was the case in 1960. A second peak of females was found in June—July of all the three years investigated. Both maxima of females were followed by high percentages of the copepodite stages I and II. High numbers of young *Calanus finmarchicus* were also found in September without a preceding peak of females. The material from Eggum 1960—1962, may then lead to the conclusion that there are two spawnings of *Calanus* per year; one in March and one in June—July. The young copepodites found in September may have been transported into the area from nearby populations, as suggested by Wiborg (1954). According to Wiborg there were three spawnings of *Calanus* at Eggum; in April, June and August—September. However, also in this material the last maximum of young copepodites was not preceded by a peak of females.

Skarsvåg (Fig. 10)

A maximum of females occurred each year in March—April, followed by high percentages of the copepodite stages I and II in April and May, so the spawning probably took place mainly in the first half of April. A second spawning occurred in July, as high percentages of females were found in July and the copepodite stages I and II in August.

High percentages of the copepodite stage V in the deeper water during the second spawning indicate that the spawning was of minor importance.

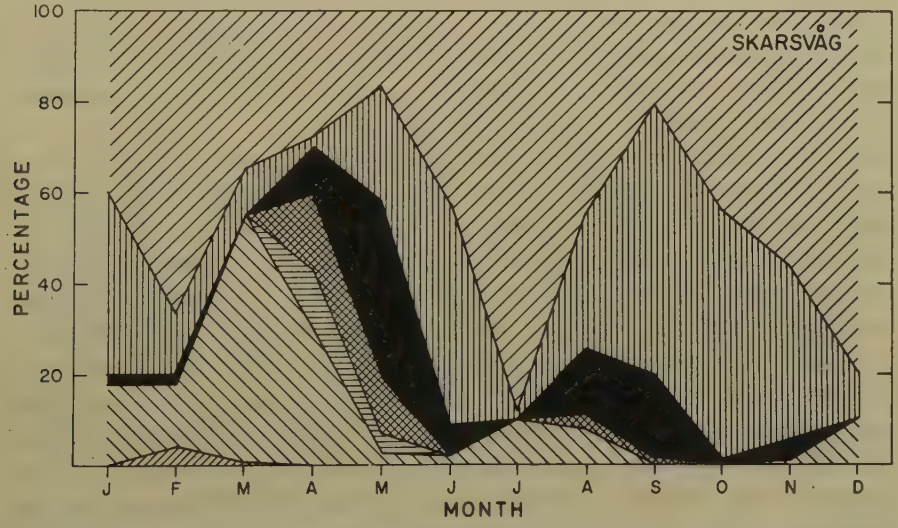

Fig. 10. Variations in the percentage distribution of males, females and copepodite stages I—V of *Calanus finmarchicus* at Skarsvåg. Monthly mean figures 1959—1962. Symbols as in Fig. 7.

No previous investigations on the propagation of *Calanus finmarchicus* from a comparable latitude in Norwegian waters have been made. According to YASHNOV (1939b) and MANTEIFEL (1939) there is only one spawning of *Calanus* per year in the southern Barents Sea and in the waters off the west Murman coast. However, according to MANTEIFEL (1941), copepodite stages I—III are found in some years from July to September in the Barents Sea without a preceding abundance of adults. MANTEIFEL concluded that these young *Calanus* were brought into the Barents Sea from Norwegian coastal waters, which supports the conclusion in the present paper that there is a second spawning in July in northern Norway.

Kongsfjorden

The scarcity of samples from this station allows no conclusions about the propagation of *Calanus finmarchicus*. The material indicates, however, that there is only one spawning per year and that no spawning takes place in the second half of the year.

DISCUSSION

At all stations along the Norwegian coast there were two pronounced maxima of volumes of zooplankton per year, while Kongsfjorden at Spitsbergen showed only one maximum. There was a significant delay in the occurrence of the spring maximum with increasing latitude, ranging from April at Sognesjøen to July at Skarsvåg. A similar trend for the occurrence of the second peak could not be detected.

A complete comparison of the annual relative richness of the zooplankton from the different stations was not possible because the material collected during the winter season was too scanty for some of the stations. However, the material was fairly good for all the stations during the period April to August, and in Table 1 is shown the mean zooplankton volumes for the different stations during this period of each year.

Table 1 indicates the relative richness of zooplankton at the different stations during the period April—August. However, one cannot draw any conclusions about the relative annual richness of the stations from the table because the plankton biomass during the last half of the year is considerably higher at Skarsvåg and Kongsfjorden than at the other stations.

The total annual biomass per station seems to be of the same order of magnitude at the four northern stations, while the biomass at Sognesjøen

Table I. Mean of monthly mean volumes in ml of zooplankton per m^2 surface from the permanent stations for the period April—August of the years 1959—1962.

Station	Year				Mean
	1959	1960	1961	1962	
Sognesjøen	10.5	8.6	No data	5.0	8.2
Skrova	19.5	46.4	25.6	27.5	29.8
Eggum	No data	20.4	32.9	31.8	28.2
Skarsvåg	31.9	12.2	12.1	15.9	18.0
Kongsfjorden	20.4	12.9	11.3	26.8	17.7

is considerably lower. This finding is supported by earlier investigations (Wiborg 1954, 1958, 1960).

Wiborg (1954) found that the richness of the zooplankton at Eggum during the spring and summer was comparable to the conditions at Georges Bank off the east coast of North America and in the Barents Sea. During the winter the zooplankton density at Eggum and Sognesjøen is extremely low, and Wiborg suggests that the strong north-going currents may carry the plankton away.

The data do not allow for conclusions as to which year was the richest because of the variation from one station to another with no general trend.

The data from the permanent stations during 1959—1962 revealed significant changes in the number of spawnings for *Calanus finmarchicus* and the time for their occurrence with increasing latitude. At Sognesjøen and possibly at Skrova three spawnings were observed, at Eggum and Skarsvåg two, and at Kongsfjorden only one. The spring spawnings occurred in the first half of March at Sognesjøen, in the last half of March at Skrova and Eggum, in the first half of April at Skarsvåg and some time between April and June at Kongsfjorden. A similar delay in the occurrence of the second spawning with increasing latitude could not be detected.

The spring spawning of *Calanus* was always followed by a sharp increase in the volumes of zooplankton, and the maximum volume was reached 1½ to 2 months after the spawning. A similar increase in the volume after the second spawning was less pronounced. This may be attributed to the fact that only a small part of the stock of *Calanus* took part in the spawning, that plankton is transported into the area from nearby regions, and that neritic species are much more abundant during the late summer, reducing the relative importance of *Calanus finmarchicus*.

An attempt was made to determine the stage distribution of *Calanus* when maximum volume occurs. Although there are considerable variations from one year to another, it is probably permissible to conclude that maximum volume is found when the copepodite stages III and IV in southern Norway and IV and V in northern Norway comprise more then 50% of the total number of *Calanus*. The relationships between the stage distribution of *Calanus finmarchicus* and the occurrence of maximum volumes should be studied more extensively, especially in boreal oceanic waters where the dominance of *Calanus* is more pronounced. This relationship might enable us to determine from a small number of samples the immediate future changes of the plankton biomass, which would be of main concern for the prediction of food availability for plankton feeding fishes.

SUMMARY

1. Zooplankton has been collected in vertical hauls from 1959 to 1962 at four permanent oceanographic stations along the coast of Norway and one from Spitsbergen. The volumes have been measured and the stage composition of *Calanus finmarchicus* determined.
2. A delay of occurrence of maxim volume with increasing latitude for the spring maximum of volume is evident, but a similar trend for the secondary maxima could not be demonstrated. The annual richness of zooplankton on the southernmost station (Sognesjøen) was considerably poorer than at the other four stations. At these the amount of zooplankton was of the same order of magnitude. There were large variations in amount of zooplankton from one year to another at all stations, and a general conclusion about the relative richness of the different years could not be made.
3. A significant delay in the time of spawning of *Calanus finmarchicus* and decreasing number of spawnings with increasing latitude was demonstrated.
4. Maximum of volume occurred about 1½ to 2 months later than the spawning of *Calanus finmarchicus* when the copepodite stages III and IV in southern Norway and IV and V in northern Norway comprised more than 50% of the stages. A method for prediction of biomass changes based on development-stage distribution of *Calanus* is suggested.

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DISTRIBUTION OF MACKEREL EGGS AND LARVAE IN THE SKAGERRAK, 1957—1959

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INTRODUCTION

The Skagerrak is one of the most important spawning areas for mackerel (*Scomber scombrus* L.) in Nordic waters: the planktonic eggs and small larvae are found in considerable numbers in June—July, especially off the south coast of Norway (Ehrenbaum 1923). The following data on the geographical distribution of mackerel eggs and larvae in the Skagerrak during different parts of the spawning season have been collected between May and July 1957—1959 in connection with a spawning study of sprat (*Clupea sprattus*) and made available by the Marine Biological Station at Flødevigen.

MATERIALS AND METHODS

Samples were collected from the middle of May to the beginning of July with a plankton net 1 m in diameter lowered to a depth of 50 or 100 m and hauled up vertically. On most stations two hauls were made, one A-haul always from 50 m to the surface, and one B-haul sometimes from 50 m, otherwise from 100 m.

In all, 495 hauls were made at 269 stations in the Skagerrak and Oslofjord. In the Skagerrak all stations were outside the skerrygard, but mackerel are known to spawn frequently further inside the fjords as well (Dannevig 1948).

Description and sizes of mackerel eggs are given by many authors (e.g. Holt 1893, Buchanan—Wollaston 1911, Dannevig 1919, Ehrenbaum 1923, Bigelow and Welsh 1925, Demir and Arim 1957 and Hiemstra 1962). Identifications were based mainly on structural characteristics, as well as on size of eggs and of the oil droplet. Eggs diameters vary with the salinity of the waters and the geographical locality: in the North Sea and Skagerrak eggs are reported to be 0.95—1.38 mm in diameter (usually 1.2—1.3 mm), the oil droplet 0.28—0.35 mm. This

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was in general the case with the present material, but a few eggs were found (identified by the embryo) measuring up to 1.45 mm in the brackish Kattegat waters late in the season.

Some eggs without embryo were indistinguishable from those of the ling (*Molva molva*), which according to EHRENBAUM (1905—09) have a diameter of 0.97—1.13 mm, with an oil droplet diameter of 0.28—0.31 mm. However, as the main spawning of ling takes place in April, and as practically no ling eggs with embryo were found, this source of error is probably an insignificant factor in the identification.

Larvae were identified on the basis of descriptions by CUNNINGHAM (1891) and EHRENBAUM (1905—09 and 1923) and measured to the nearest 0.1 mm.

Larvae and, in 1959, eggs from all stations were identified. In 1957 and 1958 the eggs from A-hauls only were identified. From the 269 A-hauls a total of 31,469 mackerel eggs and 2,914 larvae were collected (Table 1).

Table 1. Number of mackerel eggs and larvae in A-hauls.

Year	Date	Number of stations	Eggs		Number of larvae			
			Number	Without visible embryo	Total length in mm			Total
					<4.05	4.05–4.50	>4.50	
	Skagerrak							
1957	21/5—30/5	42	1 268	87%	—	—	—	—
1957	7/6—13/6	21	2 274	82%	7	6	—	13
1958	29/5— 9/6	36	8 505	59%	—	1	—	1
1958	23/6—25/6	22	3 305	62%	218	70	23	311
1958	30/6— 3/7	27	2 576	32%	202	64	53	319
1959	19/5—22/5	27	3 292	38%	7	—	—	7
1959	8/6—11/6	28	9 302	29%	1 329	435	79	1 843
1959	30/6— 2/7	18	237	37%	7	2	3	10
Total		221	30 759		1 768	578	158	2 504
	Oslo-fjord							
1957	23/5—24/5	16	71	18%	—	—	—	—
1958	29/5—31/5	16	141	98%	—	—	—	—
1959	12/6—13/6	16	498	28%	210	176	24	410
Total		48	710		210	176	24	410
Grand total		269	31 469		1 978	754	182	2 914

RESULTS

Table 1 shows the number of stations on different cruises and gives the numbers of mackerel eggs and larvae in various size-classes in the A-hauls. Only 182 (6.2%) larvae were longer than 4.5 mm, probably a result of heavy mortality, known to be 10—14% per day in American Atlantic waters (SETTE 1943), and also of the fact that the larger larvae may by better able to escape the nets (AHLSTRØM and NAIR, cited in MARR 1956).

Depth of eggs and larvae

The eggs and small larvae are free-floating, at a depth which varies according to the density of the waters. Larvae, especially those longer than 5 mm, are known to move to upper layers for the night (JOHANSEN 1925b and SETTE 1943).

No attempt was made to find the accurate depths of eggs and larvae. The following observations, however, may be indicative:

In 1959 there were on the average only a few more eggs and larvae in B-hauls taken from 100 m than in A-hauls (Table 2). This is, however, not definite evidence for the occurrence of eggs and larvae between 50 and 100 m, as wind and current will sometimes lead the net to surface more obliquely from 100 than from 50 m, thus resulting in relatively larger catches from the upper water layers of the B-hauls. The number of eggs in B-hauls was 114% that of A-hauls, larvae in B-hauls 125% that of A-hauls, and the difference between A- and B-hauls was significantly greater ($P < 0.001$) for larvae than for eggs. This might indicate that a few of the larvae (but very few, if any, of the eggs) were taken below 50 m.

If this is the case, net samples taken from 50 m and upwards should be sufficient for investigating mackerel spawning localities.

Spawning period

In the North Sea and Skagerrak spawning takes place from the second half of May and into the month of July with a maximum in June (EHREN-

Table 2. Number of mackerel eggs and larvae from Skagerrak stations in 1959.

	A-hauls 50—0 m	B-hauls 100—0 m	Number in B-hauls as percentage of that in A-hauls
Eggs	9 890	11 289	114.1%
Larvae	2 005	2 499	124.6%

BAUM 1923, JOHANSEN 1925a, REVHEIM 1951 and DANNEVIG 1962); the earliest record along the Norwegian coast is 14 May (DANNEVIG 1948). Cases of very late spawning are known from British waters where the peak occurs in May—June (ALLEN 1917, LEBOUR 1918, CLARK 1920, CORBIN 1947 and STEVEN 1949) but from the present data nothing can be said about the conditions after 3 July.

Mackerel eggs were found on all cruises, i. e. from 19 May to 3 July. In 1959 great quantities were found as early as 19—22 May (an average of 122 per haul), and as many as 62% had visible embryos (Table 1). That year the first larvae were found on 22 May off Lindesnes, all in the egg-sac stage. In 1957 eggs were also collected late in May (21—30 May, 30 eggs per haul, 13% with visible embryos), but no larvae were found at any of the many stations investigated. In 1958 the first cruise was from 29 May to 9 June, and a great number of eggs, but only one larva, was found. These data indicate that in 1959 heavy spawning started as early as the middle of May, in 1957 and probably also in 1958, in the last days of May.

In 1957 there was no cruise after 13 June. In 1958, around the first of July, the average number of eggs and larvae per sample was 95 and 12 respectively. Greatest averages per haul (332 eggs and 66 larvae) were taken about 10 June 1959; around 1 July of that year the average had fallen considerably (to 13 eggs and 0.6 larvae), indicating that in this year with an early start, spawning was practically over at the beginning of July.

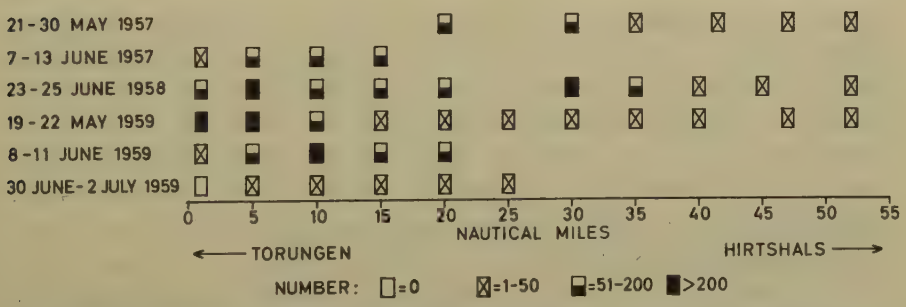

Fig. 1. Number of mackerel eggs collected in A-hauls on different cruises from Torungen, Norway to Hirtshals, Denmark.

Spawning area

Mackerel eggs were found at all localities, in all parts of the Skagerrak.

Figure 1 shows the number of eggs collected on different cruises from Torungen off Arendal to Hirtshals. Early in the season large quantities were found mainly off the Norwegian coast, (e.g. 19—22 May, 1959)

but later great numbers were found further out as well; few eggs were ever taken off the Danish coast.

The data as a whole show the same tendencies, with the largest quantities of eggs found along the Norwegian and Swedish Skagerrak coast, especially between Jomfruland (Kragerø) and Väderøbod. The greatest number in one haul (937) was taken 4 nautical miles south of Ferder Light (Tønsberg) on 11 June, 1959.

From cruises in the Oslofjord, the only significant quantities of mackerel eggs or larvae were collected in 1959, off Drøbak. In the inner fjord the number was always negligible.

As the eggs float passively, a study of this type cannot indicate exactly where spawning has taken place. However, as hatching probably takes about one week in natural conditons (Worley 1933 and Sette 1943) even the oldest eggs had not been adrift for more than a few days. Along the Norwegian coast Baltic Water runs westwards near the surface, with lowered salinity in the spring owing to the melting of snow. In late spring and summer this water is warmer than the surrounding waters, and in summer its spreads out over the Skagerrak as a result of its low specific gravity (Dannevig 1933 and Schulz 1940).

As mackerel usually spawn near the surface (Dannevig 1962) and as the eggs and larvae are usually found in the Baltic Current, it seems a fair assumption that spawning also takes place mainly in this current, but further "upstream" than the localities registered for the eggs and larvae.

Temperature

According to Dannevig (1962) mackerel generally spawn in waters of about 12°C. The eggs found earliest in the Norwegian part of the Skagerrak occurred at a temperature of 8° (Dannevig 1948). From other waters the main bulk of spawning seems to take place from 11° to 14° (Johansen 1925a, Gall 1939, Sette 1943 and Kändler 1954), with extremes in American Atlantic waters of 7.3—17.6°C (Sette 1943). Spawning is thus not "restricted to any fixed degree of temperature" (Ehrenbaum 1923b, p. 6).

To characterize temperature conditions at the different stations the average temperature at a depth of 0 and 10 m is used as spawning is believed to occur in the upper water layers (Dannevig 1962), at least early in the season.

According to Table 3 the highest concentrations of eggs prior to 11 June were found in the warmest areas of the Skagerrak. The same tendency was noted also on individual cruises, in May at least; later, in the summer water temperatures were evidently high enough in all parts of the sea.

Table 3. Number of mackerel eggs collected per haul in relation to water temperature. (The cruise of 30 June to 2 July 1959, is excluded (average temperature 14.2°) as no station had more than 50 eggs).

Date	≤ 50 eggs			51—200 eggs			> 200 eggs		
	Number of Stations	Temperature		Number of Stations	Temperature		Number of Stations	Temperature	
		Mean	Extremes		Mean	Extremes		Mean	Extremes
19/5–11/6	67	9.9	8–12.5	41	10.9	9–13.5	47	12.9	9.6–15.9
23/6– 3/7	16	14.8	13–17.3	25	14.4	11.7–16.7	8	13.5	11.3–15.9

Hauls of over 200 eggs were, with one exception, all taken between 10° and 16°C. Only 6 hauls of 51—200 eggs were made in waters below 10° (3 of them at stations where even the maximum temperature was below this). Thus it seems probable that spawning takes place mainly between 10° and 16°C.

Salinity

Mackerel usually spawn in waters with a salinity of about 34‰ (Farran 1939, Furnestin 1939 and Gall 1939); in the Skagerrak and Kattegat the eggs are seldom found in waters whose salt content is less than 26‰ (Nilsson 1914).

Table 4 shows the number of eggs collected in relation to salinity given as the average of measurements at 0 and 10 m. In very brackish

Table 4. Number of mackerel eggs collected per haul in relation to salinity in ‰. (East and West Skagerrak — east and west respectively of a line from Risør, Norway to Skagen, Denmark).

Date	≤ 50 eggs			> 50 eggs		
	Number of stations	Salinity		Number of stations	Salinity	
		Mean	Extremes		Mean	Extremes
East Skagerrak						
21/5—11/6	41	28.8	21.4–33.1	54	25.5	20.3–31.6
30/6– 3/7	11	23.9	17.7–29.8	16	25.2	21.3–32.9
Total	52	27.8	17.7–33.1	70	25.4	20.3–32.9
West Skagerrak						
19/5–11/6	26	32.4	28.8–34.4	34	29.4	28.1–33.2
23/6–25/6	6	27.6	26.9–28.4	16	28.0	22.9–29.2
Total	32	30.5	26.9–34.4	50	28.7	22.9–33.2

areas, however, the eggs were probably taken from greater depths and more saline waters than the surface measurements indicate.

In the eastern Skagerrak the upper layers in the spawning centres had an average salinity of 25.5‰, in the western Skagerrak, 28.7‰. Before 11 June salinity was a little lower in the centres than elsewhere.

DISCUSSION

Mackerel usually winter at great depths in the North Sea and Skagerrak (Revheim 1955, Nedelec 1958) and migrate in April—May towards the coast, where spawning takes place in waters which are relatively warm and of low salinity.

Comparing the Skagerrak with other areas, where mackerel move *from* the coast in spring, Steven (1948) suggests that this "spawning" migration is primarily directed towards deeper waters. Although this may be true in part, it is possible that, in the Skagerrak at least, the mackerel are migrating to those parts of the sea where temperature conditions are most suitable for spawning. In the Kattegat the numbers of spawning mackerel seem to be dependent on the strength of the in-running current (Jensen 1960), indicating that still other factors, such as deep-water currents and hydrographic conditions, may influence the migrations.

In 1959 spawning apparently started earlier than in 1957 and 1958, and, according to Table 5, May temperatures in coastal waters were higher in 1959 than in the two preceding years, indicating a relationship between high May temperatures and early spawning. The commencement of spawning probably also depends on other factors such as winter temperatures (Steven 1949), and in some years a region of cold water just below the surface might inhibit mackerel from coming to the upper layers (Dannevig 1952).

Table 5. Average temperature at sea surface in the month of May.

Locality	Author	1957	1958	1959
Flødevigen, Norway	G. Dannevig pers. comm.	9.1	7.1	11.1
Anholt, N. Denmark	Thomsen 1959, 1960, 1961	9.2	8.3	11.1
"Vinga", Sweden.....	Jerlov 1959 and Svansson 1960, 1961	9.1	8.3	11.2

SUMMARY

Numbers of mackerel eggs and larvae collected from 495 vertical hauls at 269 stations in the Skagerrak and Oslofjord, 1957—59 are analysed.

Eggs were found in practically all areas of the Skagerrak during the sampling period: from the middle of May to the beginning of July.

A few larvae, but very few if any eggs, were probably taken from below a depth of 50 m.

Early in the season spawning seems to take place mainly in the comparatively warm waters of low salinity in the Baltic Current. In 1959 spawning started about mid-May, in 1957 and 1958 in the last days of May; in 1959 May surface temperatures were higher than in the two preceding years. Spawning seems to take place mainly in water temperatures of 10—16°C.

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THE MIGRATION OF NORWEGIAN HERRING TO ICELANDIC WATERS AND THE ENVIRONMENTAL CONDITIONS IN MAY—JUNE, 1961—1964

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INTRODUCTION

Since 1949 the migrations of herring in the Norwegian Sea have been intensively studied. It has been shown that the time and place of their migration to the spawning grounds along the west coast of Norway are closely related to hydrographical conditions, particularly temperature (Devold 1951). During the feeding migration in summer the hydrographical conditions are also important in determining the distribution and formation of herring shoals (Devold 1963, Jakobsson 1963), but several scientists have shown that there is also a connection between plankton conditions and the migration pattern of feeding herring. Reviews of work on the plankton/herring relationship have been given by Pavshtiks (1956) and Jakobsson (1958, 1962).

The most extensive investigations on the migrations of Norwegian herring in the Norwegian Sea in relation to plankton have been carried out by Pavshtiks (1956). She found that after spawning the older age groups were feeding mainly on the wintering stock of *Calanus finmarchicus* in the coastal or Atlantic water, and later in spring in the water of the East Icelandic Current; they thus followed the shift in spawning time of *C. finmarchicus*. The migration routes of the herring were closely related to the seasonal changes in distribution and production of plankton. Annual fluctuations in time of the biological spring may, therefore, cause a change in the feeding migration of the herring.

The Norwegian investigations on herring migration in the Norwegian Sea during May and June have been conducted since 1951 in collaboration with Denmark (until 1961), Iceland and U.S.S.R. (from 1957). During the years 1961—1964 the Norwegian part of the joint work has been confined to the areas from the Faroes along the east and north-east coast of Iceland to Jan Mayen. The observations on herring, temperature and zooplankton during these years provide the material for the present

study which demonstrate the migration of Norwegian herring to the north-east coast of Iceland in relation to environmental factors. A summary of the work has been given annually in the joint reports to the Herring Committee of ICES (Jakobsson and Østvedt 1961, Anon 1964a, 1963 and 1964b).

MATERIAL AND METHODS

In 1962, 1963, and 1964 the investigations were carried out along the same sections with stations 20 or 40 miles apart (Figs. 3, 5 and 10) and during approximately the same period (in 1962: 26 May—8 June, 1963: 22 May—5 June, and 1964: 27 May—10 June). Additional observations were made each year until about 20 June. In 1961 the first survey on the east and north-east coast of Iceland was undertaken during the period 7—17 June.

Measurements of temperature and salinity have been made at each station at standard depths down to 500 meters. Surface temperature (at 4 m) was measured by termograph. Zooplankton was collected in vertical hauls from 50—0 m. In 1961 and 1962 a Juday net (diameter 80 cm, silk no. 0) was used, in 1963 and 1964 replaced by a standard Hensen net (diameter 70 cm, silk no. 3). The volume of each sample was measured by the displacement method and stage composition of *C. finmarchicus* determined by counting 100 individuals of the species (short cut method, Hallgrimsson 1958). The percentage occurrence of copepodite stages I—III combined, is shown on the figures as 25 percent, 50 percent and 75 percent isolines.

During these investigations herring shoals were located with sonar and echo sounders and drift nets were frequently used for sampling the herring.

RESULTS

1961

The distributions of herring and temperature at 20 m depth in the period 7—17 June are shown in Fig. 1. Herring shoals were recorded 60—70 miles north-east of Langanes on 9 June. During the following week the herring evidently moved north-westward and dense concentrations were recorded north of Melrakkasletta in the second half of June. According to Jakobsson and Østvedt (1961) the temperature at 20 m depth on the north-east coast of Iceland was somewhat above average (mean temperature for the period 1950—60 as given by Stephanson (1962). In the area where the herring occurred, the temperature at 20

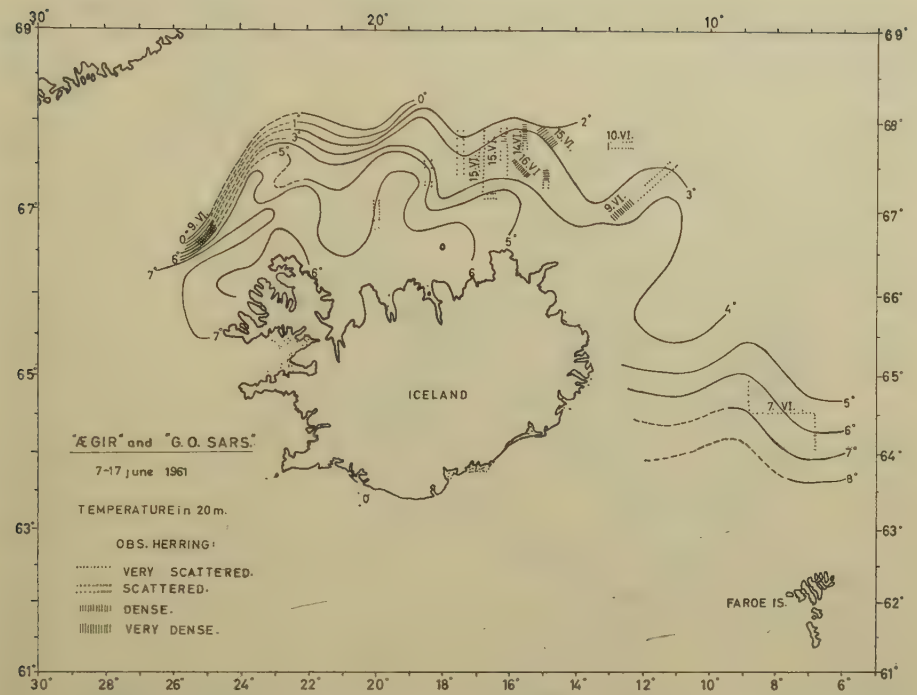

Fig. 1. Herring distribution and temperature at 20 m, 7—17 June 1961 (from JAKOBSSON and ØSTVEDT 1961).

m varied from 2° to 4°C. Off the north coast of Iceland the zooplankton was also more abundant than in previous years, while off the east coast it was about normal. During June the herring shoals were generally encountered in areas with low zooplankton densities and less than 25 percent of *C. finmarchicus* in stages I—III, i.e. in areas where the older stages predominated, presumably the wintering stock (Fig. 2).

According to JAKOBSSON (1962), 24.8 per cent of the Icelandic herring catch in 1961 was taken in the area north of Melrakkasletta during three weeks in June—July. Later in the summer the herring migrated to the traditional fishing grounds on the east coast of Iceland where young copepodites (stages I—III) of *C. finmarchicus* predominated in the beginning of June. In July copepodites had probably metamorphosed to older stages, constituting more suitable food for the herring.

1962

In 1962 the investigation started in the last week of May and dense concentrations of herring were observed on 30 May between 40 and 110 nautical miles north-east of Langanes (Fig. 3). The shoals were mainly

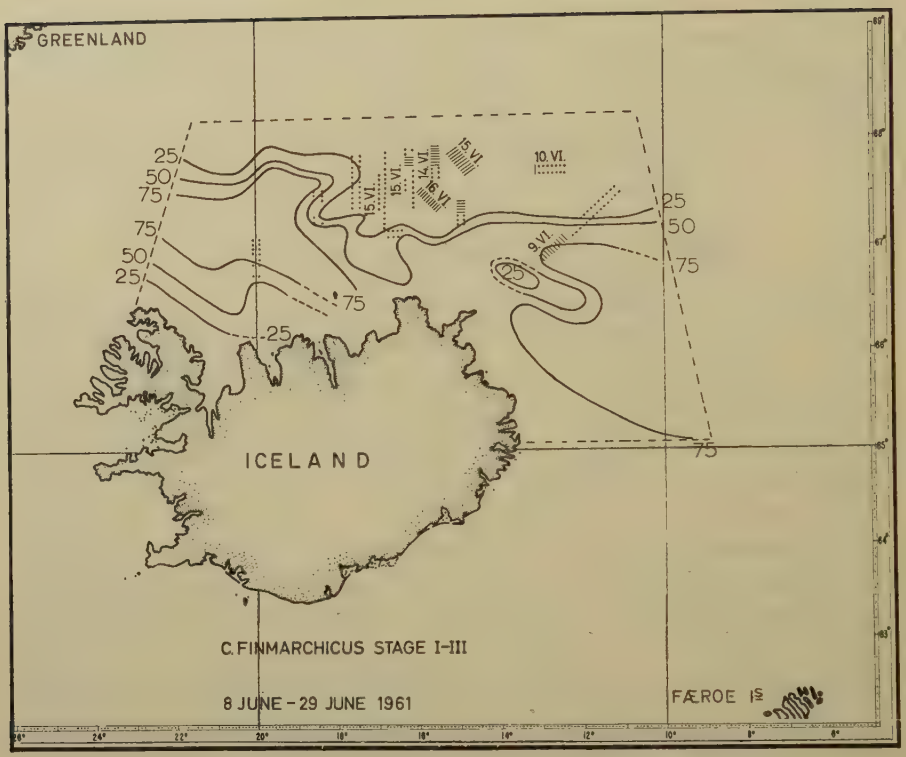

Fig. 2. Herring distribution (legend—see Fig. 1) and percentage distribution of copepodites stages I—III of *C. finmarchicus*, 8—29 June 1961.

found in waters colder than 3°C, extending into watermasses of temperature below 2°C (Anon 1964a). The herring quickly moved in a northwesterly direction and on 5 June dense concentrations were recorded north-east of Kolbeinsey. Samples of herring taken from drift net catches contained mainly Norwegian spring spawners, but it showed that the Icelandic spring spawners were also present and thus had already migrated to the north coast probably from the west, and had mixed with the Norwegian spring spawners migrating from east. During the first half of June 1962 the concentrations of Norwegian spring spawners were found much further west than in 1961.

The quantitative distribution of zooplankton off the north coast is shown in Fig. 4. In the cold waters, scarce in plankton, the wintering stock of *C. finmarchicus* was predominant while in the coastal and mixed waters off the north coast of Iceland *C. finmarchicus* in stages I—IV was abundant and the spawning had probably occurred.

In accordance with the observations in 1961 it was again found that

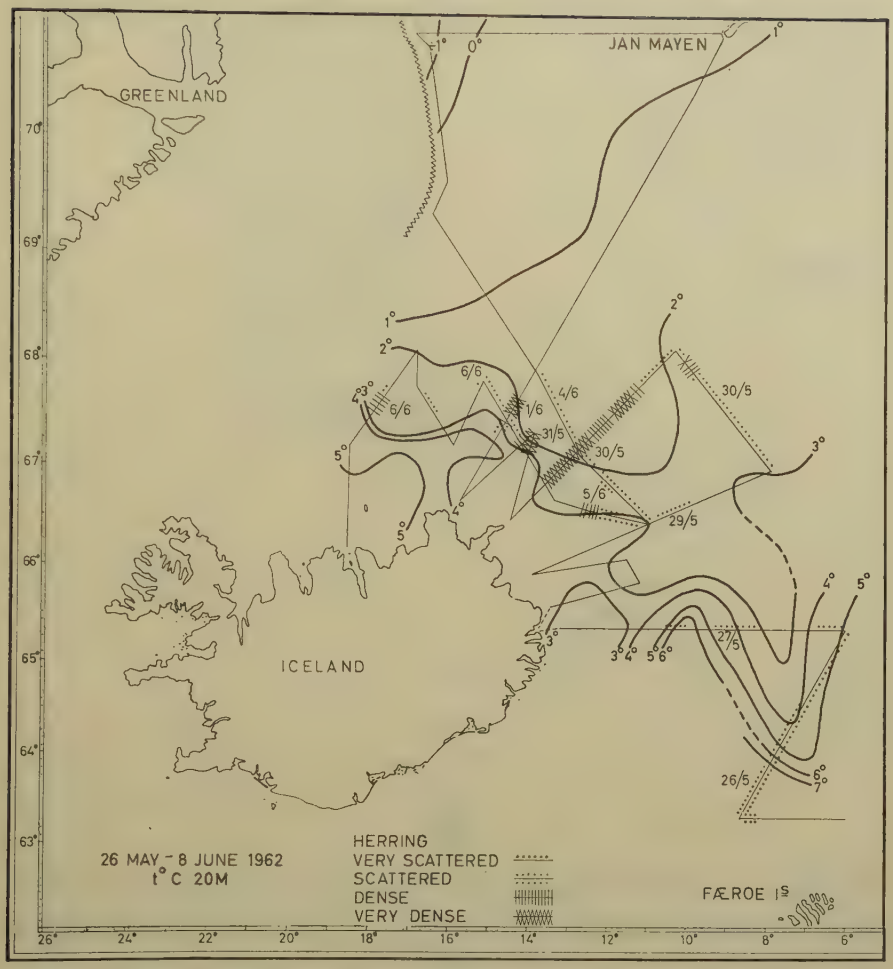

Fig. 3. Herring distribution and temperature at 20 m, 26 May—8 June 1962.

the Norwegian herring during the migration to the north-east coast of Iceland were mainly located in the cold water areas east and north-east of Langanes, where the zooplankton was relatively scarce, but with a high proportion of wintering stages of *C. finmarchicus*.

1963

The distribution of temperature and herring, east and north-east of Iceland in the period 21 May—5 June are shown in Fig. 5. Herring were recorded in two regions; in the southernmost region (between lat. 64°N and 65°N and about long. 6°W) only small shoals were found. Here the herring seem to be present nearly all the year round, mostly scattered

Fig. 4. Zooplankton volume, ml/m³ in 50—0 m, 26 May—8 June 1962 (from ANON 1964a).

over a wide area; further north, dense concentrations were found about 150 nautical miles north-east of Langanes in watermasses colder than 2°C. The vertical distributions of the herring shoals in relation to temperature are shown in Fig. 6. The shoals were found from the surface to 300 m, in water with the temperature ranging from 5° to 0°C. In the 0—200 m layers the temperature was below the average for the last ten years and the 3° isotherm was situated 120 nautical miles further south-eastwards than in 1962 (ANON 1963).

The quantitative distribution of zooplankton in the period 22 May to 5 June is shown in Fig. 7. Off the north-east coast of Iceland the zooplankton was generally scarce as compared with previous years and considerably more scarse than in 1962. The areas abundant in plankton

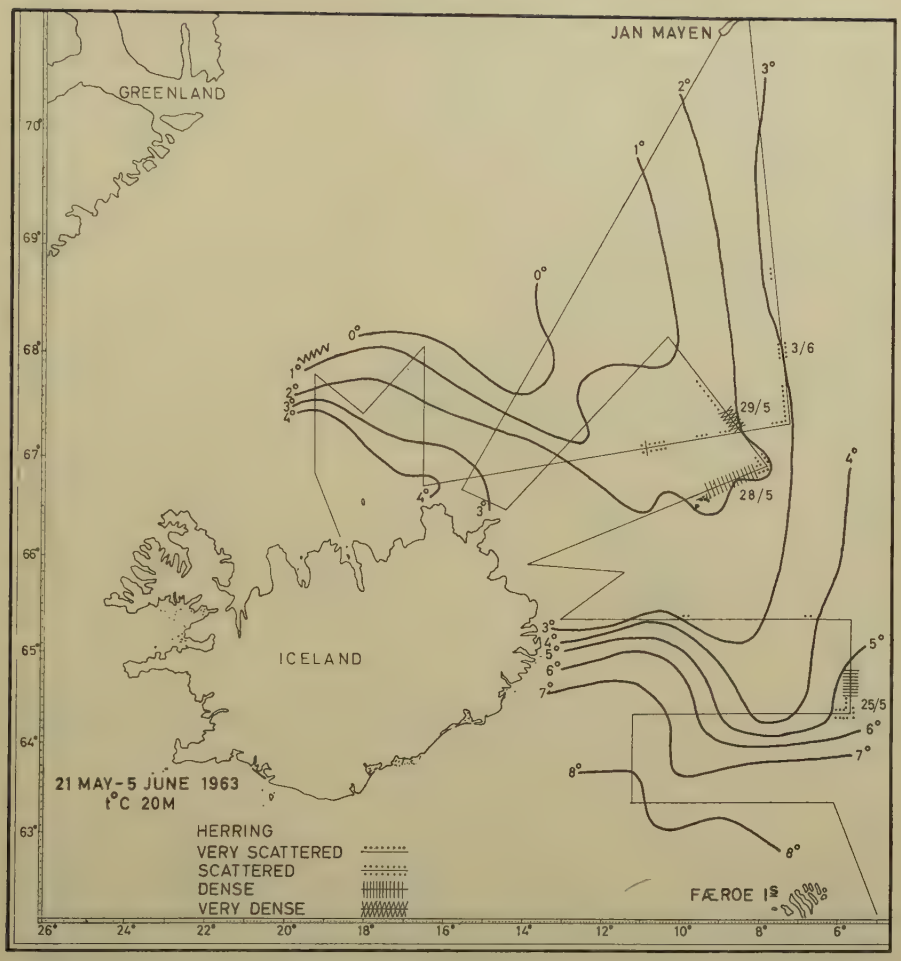

Fig. 5. Herring distribution and temperature at 20 m, 21 May—5 June 1963.

(above 1.5 ml/m³) were also situated much further off the coast than in 1962. In both years *C. finmarchicus* was the most numerous species in the plankton population also along the coast, where the densities were low. In the cold waters (besides *C. finmarchicus*) *C. hyperboreus*, *Pseudocalanus minutus*, *Themisto* spp. and *Sagitta* spp. were numerous. As in previous years the herring were found in watermasses where the older stages of *C. finmarchicus* predominated (Fig. 8).

The herring shoals observed north-east of Langanes at the end of May, seemed to move westwards, penetrating the East Icelandic Current. When the observations were repeated in the period 11—21 June, dense concentrations were found on 19 June in the area north and north-east of

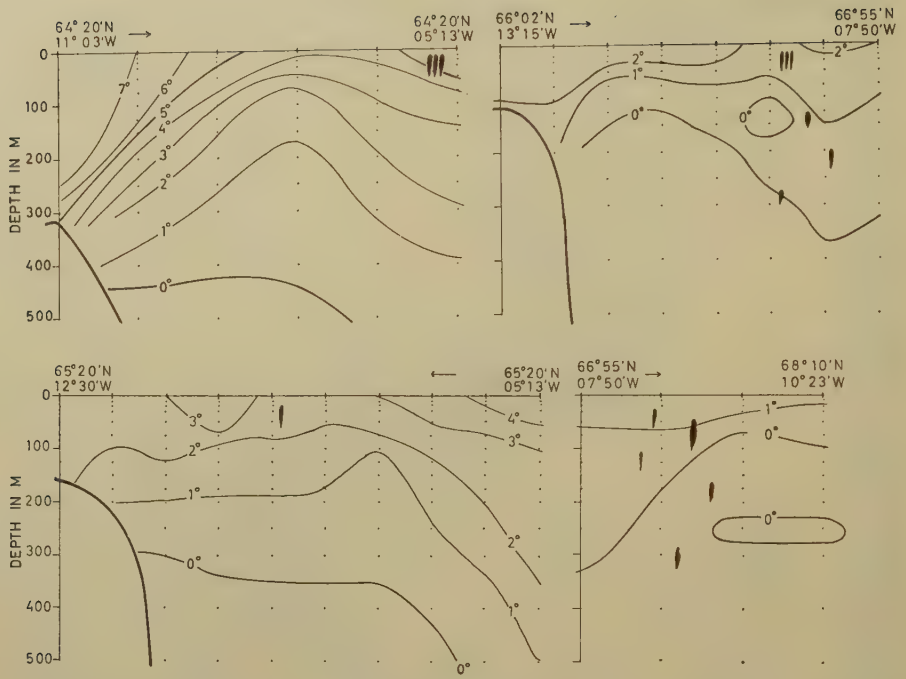

Fig. 6. Temperature sections and herring distribution east and north-east of Langanes 24—29 May 1963.

Langanes between lat. 67°N and 68°N at long. 16°W (Fig. 9). The percentage distribution of *C. finmarchicus*, stages I—III, shown in Fig. 9, indicates that during the migration to the north-east coast the herring followed the transition area between the cold water, containing a stock of wintering *C. finmarchicus* in stages IV—VI, and the mixed coastal water, containing young *C. finmarchicus* (stages I—III). In 1963 the westward migration of the Norwegian herring was delayed at least two weeks, compared with 1962 (Anon 1963).

1964

The investigation started 5 days later than in 1963. On 4—5 June, during the survey of the area east of Langanes, dense concentrations of herring were recorded 60 nautical miles off Langanes (Fig. 10). The herring were mainly observed in waters with a temperature of 2°—3°C, on the western side of the East Icelandic Current, and seemed to be moving rapidly further westwards. On 8 June, dense concentrations were recorded north off Langanes, from lat. 67°30' N to 68°30' N and between

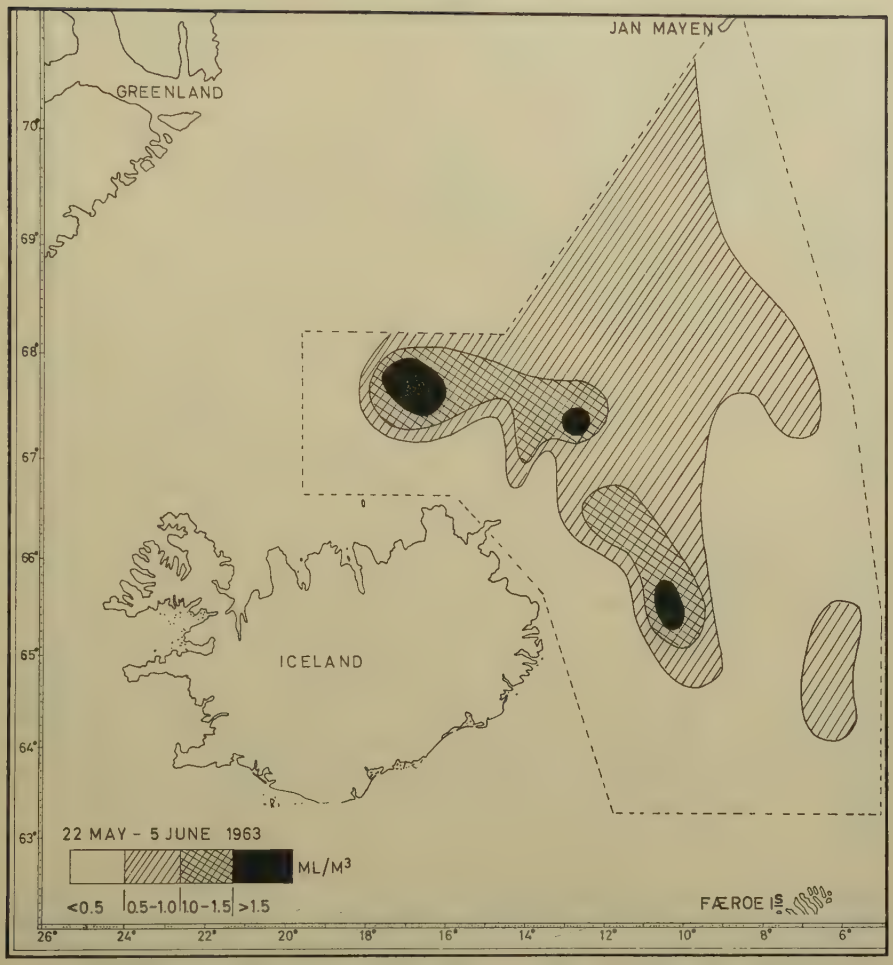

Fig. 7. Zooplankton volume, ml/m³ in 50—0 m, 22 May—5 June 1963.

long. 12°W and 16°W. Drift net samples in this area consisted exclusively of old Norwegian spring spawners with a mean length of 37.5 cm.

The temperature at depths down to 200 m off the north coast of Iceland was generally 1°C above average and 2°C higher than in 1963 (Anon 1964b). In this area the zooplankton was more scarce than in 1963, plankton volumes above 1.5 ml/m³ being recorded at only a few stations (Fig. 11). In all areas with high plankton concentrations, *C. finmarchicus* predominated.

The percentage distribution of *C. finmarchicus* stages I—III, shown in Fig. 12, indicates that only to the north of latitude 66°30' did the stock consist of less than 25 percent young copepodites. South of lat. 66°30' N

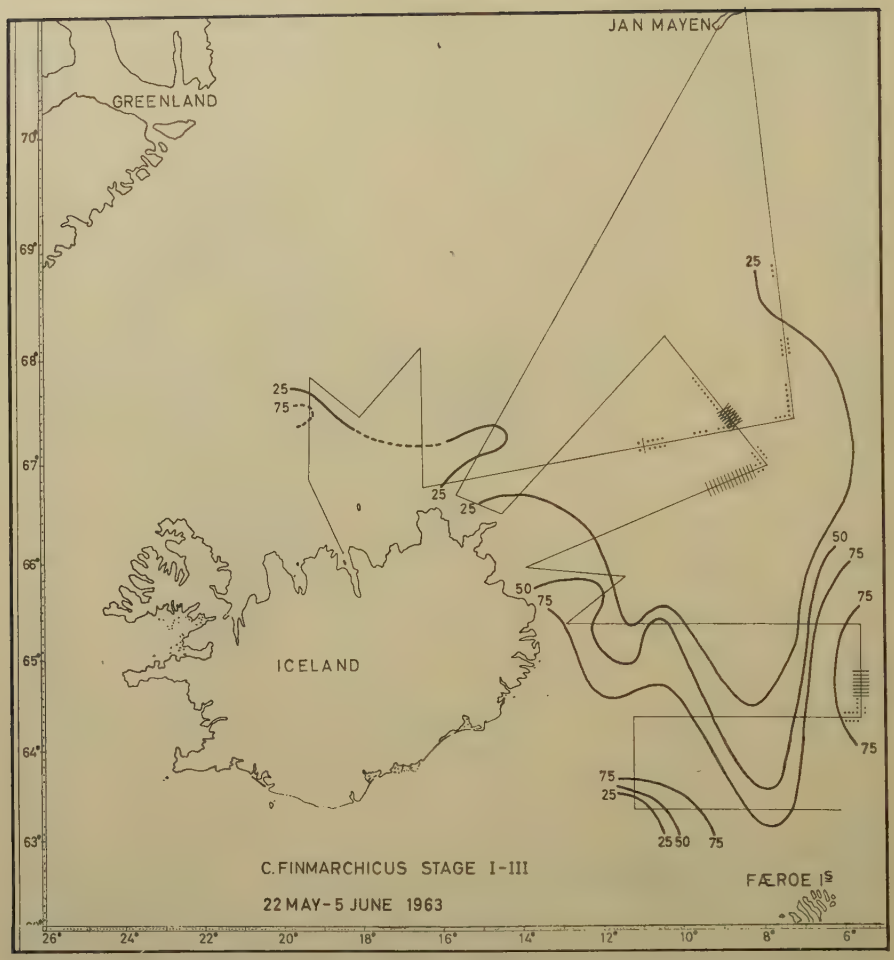

Fig. 8. Herring distribution (legend—see Fig. 5) and percentage distribution of copepodites stages I—III *C. finmarchicus*, 22 May—5 June 1963.

the spawning of *C. finmarchicus* had apparently occurred somewhat earlier than in 1963 when the stages IV—VI predominated over a much wider area. This fact may be ascribed to the higher temperature in 1964 and an early formation of a thermocline in the upper water layers off the east and north-east coast of Iceland, which resulted in an unusual early spring bloom of phytoplankton (Anon 1964b). Further evidence of this was provided by the continous transparency recordings. In 1964 much lower concentration of particles were recorded than in 1963, indicating a different situation in the phytoplankton (Berge, personal communication). The initiating effect of phytoplankton blooming on the

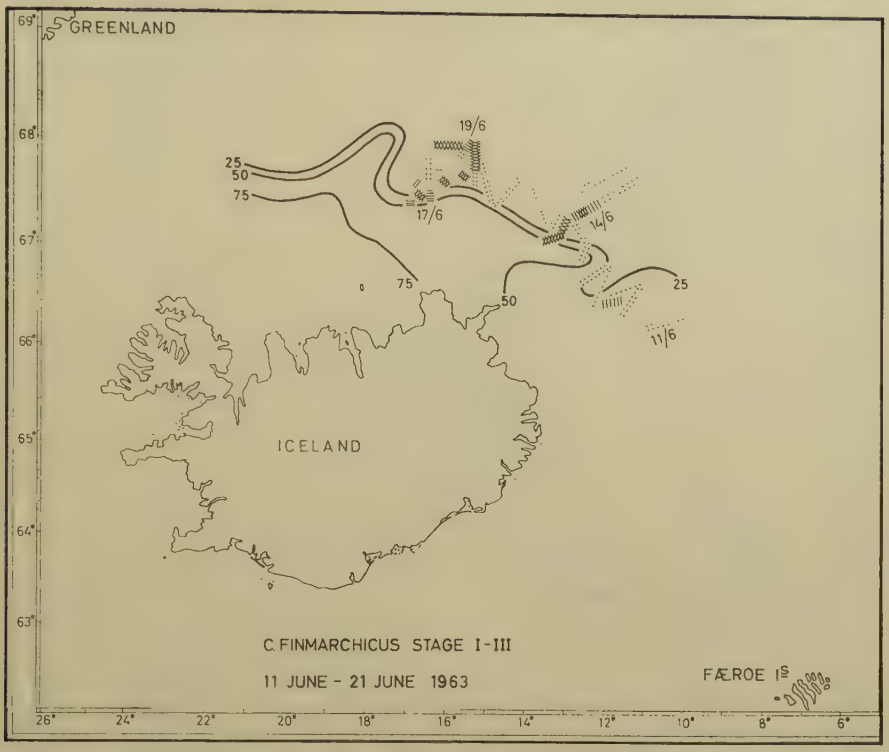

Fig. 9. Herring distribution (legend—see Fig. 5) and percentage distribution of cope podites stages I—III of *C. finmarchicus*, 11—21 June 1963.

spawning of *C. finmarchicus* has been shown by several workers (Sverdrup 1953, Marshall and Orr 1959).

In the period 11 to 20 June the temperature increased rapidly along the north-east coast and this was followed by an extension of the spawning area of *C. finmarchicus* (Fig. 13). The herring observed north of Langanes on 8 June either moved further northwards or dispersed (Anon 1964b), but during the first half of June a purse-seine fishery, by both Icelandic and Norwegian vessels took place further from the north coast of Iceland than in any previous years. On 10 June dense concentrations of herring were recorded close to the east coast of Iceland. In contrast to the herring sampled off the north coast younger individuals were also present, constituting from 5—35 per cent of the samples from drift net catches. No observations of these herring shoals were reported until they were found off the east coast. It should be noted that the invasion into the coastal waters took place when young copeodites (stages I—III) of *Calanus* were still predominant in this area.

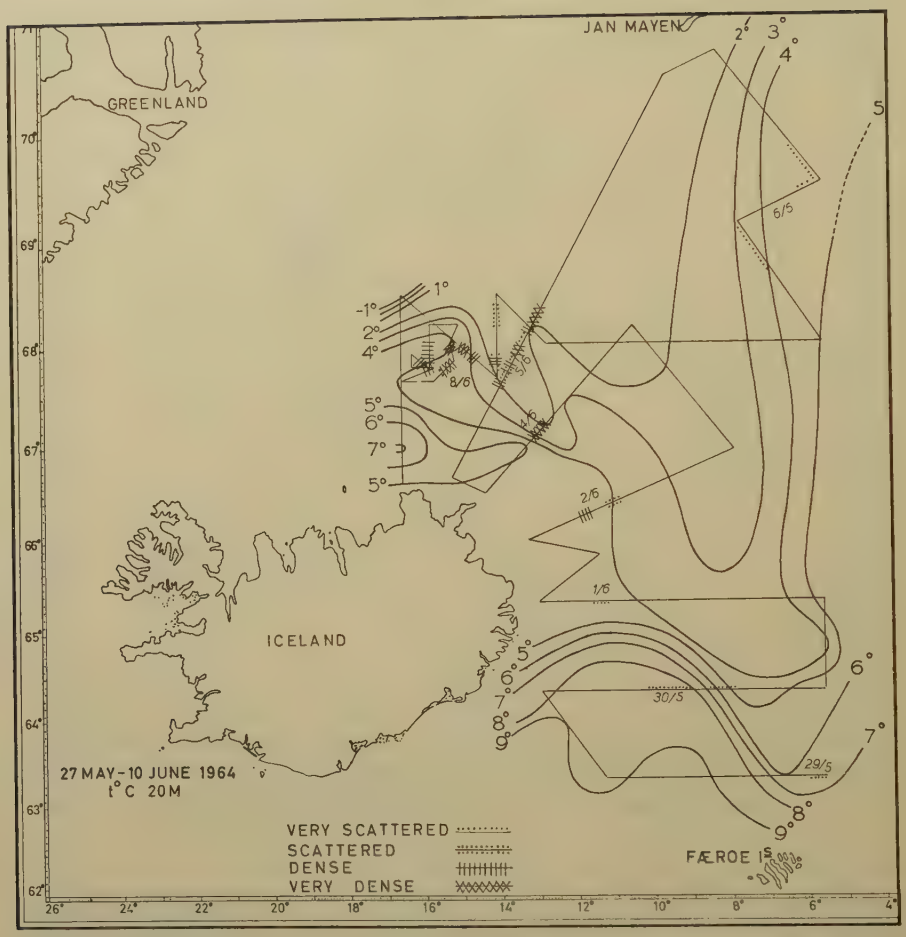

Fig. 10. Herring distribution and temperature at 20 m, 27 May—10 June 1964.

The migration pattern of the herring into North Icelandic waters in early June was similar to that in 1963, but such dense concentrations of herring, as those recorded in the first half of June close to the east coast, have usually not been observed before the beginning of July.

DISCUSSION

In the years 1961—1964 the herring were first recorded east or north-east of Langanes at the end of May and early June. During the first or second week of June the herring shoals migrated further westwards, being mainly confined to the areas between lat. 67°N and 68°N and as far west as about long. 16°W or 18°W.

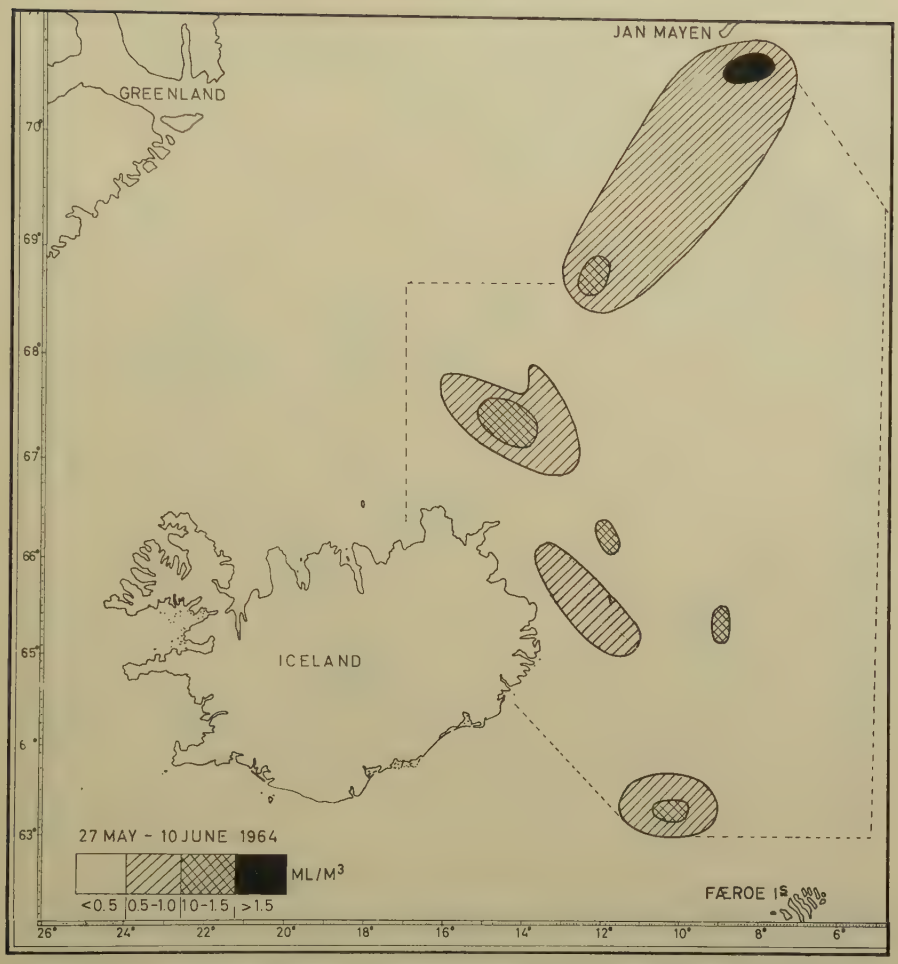

Fig. 11. Zooplankton volume, ml/m³ in 50—0 m, 27 May—10 June 1964.

In 1961 and 1962 an early influx of Icelandic spring spawners from the west was observed on the north coast of Iceland. In contrast in June 1963 and 1964, there was only insignificant, or no, migration of Icelandic spring spawners to the north coast.

During the period 1961—1964 the migration pattern of the Norwegian spring spawners to the north-east coast of Iceland in May and early June was rather similar, but variations in time were observed from year to year. In 1962 dense concentrations of herring were recorded at long. 18°W already on 5 June, but the main invasion was still west of long 14°W. In 1964 herring were observed at long. 16°W on 8 June. In 1963 no herring shoals were found west of long. 16°W until 17 June,

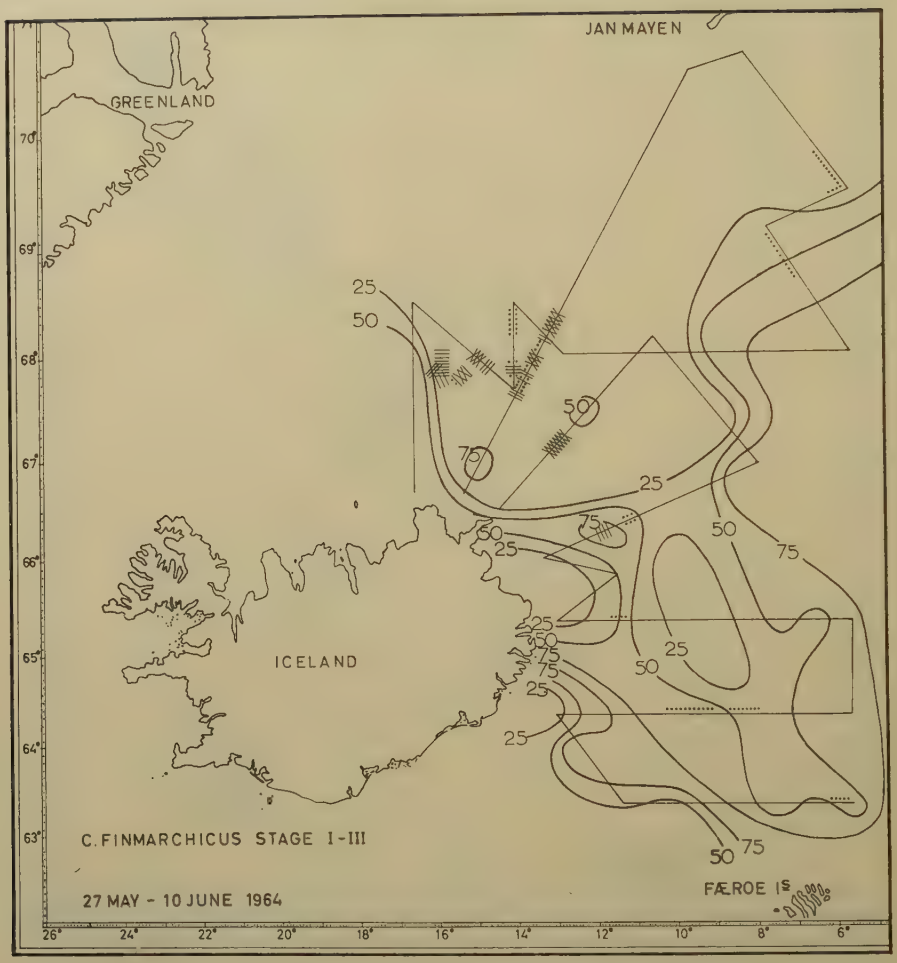

Fig. 12. Herring distribution and percentage distribution of copepodites stages I—III of *C. finmarchicus*, 27 May—10 June 1964.

and the invasion was delayed nearly two weeks as compared with 1962 and 1964. When these data are compared with the temperature conditions in June each year, there is apparently a close relationship. In 1961 the temperature in the surface layers (at 20 m) was a little above average on the north coast, while they were average off the east coast; in 1962 the temperature was close to the average values and in 1964 about 1°C above average and nearly 2°C higher than in 1963. It therefore seems that the herring during the average temperature years of 1961 and 1962 migrated to the north coast during the 1st or 2nd week of June. In the cold year of 1963 the invasion was delayed, while in the warm year 1964, it occurred early especially on the east coast.

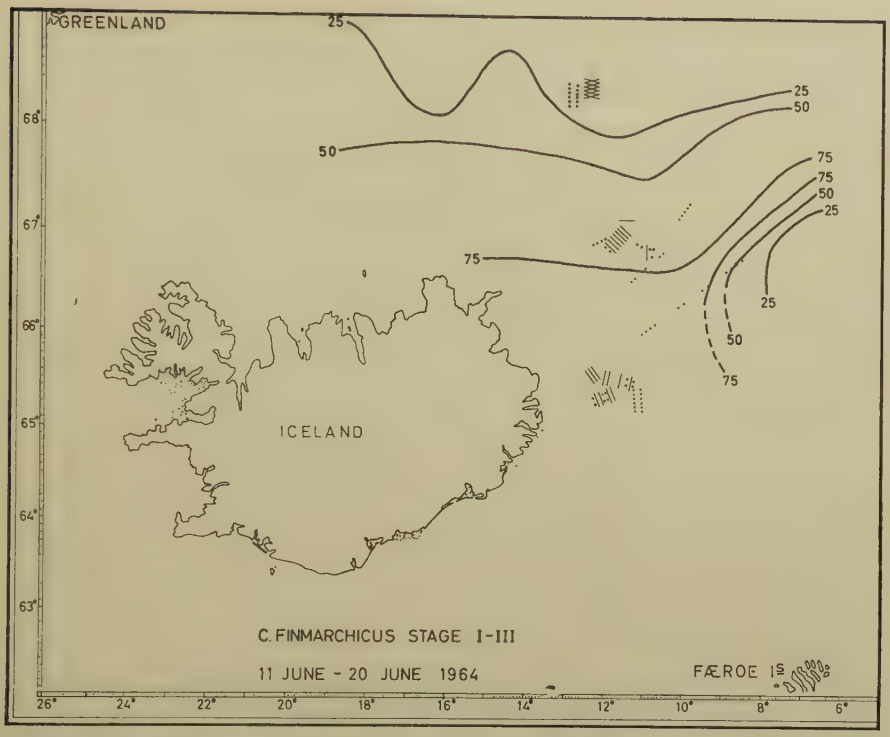

Fig. 13. Herring distribution and percentage distribution of copepodites stages I—III of *C. finmarchicus*, 11—20 June 1964.

In May-June herring shoals have been recorded in waters of temperature between 6° to 0°C and even below 0°C (Fig. 6). Although dense herring concentrations are mainly found in waters above 1°C there seems to be no clear evidence that the feeding migrations of herring are wholly governed by temperature conditions. During all the years investigated herring have been recorded east or north-east of Langenas crossing the East Icelandic Current. Pavshtiks (1956) also found that herring migrate into the cold waters (below 2°C) of the East Greenland Current.

On the Icelandic north coast fishing grounds changes in migration pattern of herring in July—August are closely related to temperature and feeding conditions (Jakobsson 1963). As temperature and plankton conditions are closely related, it cannot be doubted that the plankton conditions (or rather certain species of the plankton, in particular *C. finmarchicus*) are important for the migration pattern of feeding herring. Blaxter and Holliday (1963) also emphasized the importance of size and type of plankton in the study of plankton/herring relationships.

Pavshtiks (1956) found that nauplii and young copepodites of *C. finmarchicus* are probably too small as food for the adult herring.

Although *C. finmarchicus* usually constitutes the bulk of the zooplankton population in the Norwegian Sea, other organisms, unacceptable as herring food, may also be very abundant. In this situation a possible positive correlation between the quantitative distribution of edible zooplankton forms and herring may be masked. The present data show that during May-June herring were mainly found in areas where zooplankton was relatively scarce. During June 1958 herring were also scarce in the areas of the Norwegian Sea, richest in zooplankton (Lie 1963). On the other hand Jakobsson (1963) demonstrated a positive correlation between herring and the abundance of zooplankton, in particular *C. finmarchicus* off the north coast of Iceland in July-August.

In May and early June, stages I—III of *C. finmarchicus* usually predominate in areas with high zooplankton concentrations along the east and north-east coasts of Iceland. The older stages, IV—VI, are most abundant in the cold water further off the coast. In the years 1961—1964 the migration routes of the Norwegian herring have been confined to areas with a high proportion of stages IV—VI. These results confirm the observations by Pavshtiks (1956) and Grusov (1961) that in spring and early summer the older age groups of the Norwegian herring feed on the wintering stock of *C. finmarchicus*, nauplii and young copepodites being too small to serve as food.

According to Hallgrimsson (1960) the growth condition for zooplankton in North Icelandic waters depends on the mixing processes of the water masses off the north-west coast. Furthermore the strong oceanic fronts and the favourable growth conditions for zooplankton near these fronts are the environmental factors which primarily affect the herring fishery north of Iceland. Several authors (Fridriksson 1944, Einarsson 1957, Jakobsson 1960) have stressed the importance of the abundance of *C. finmarchicus* on the shoaling behaviour of the herring and consequently on the herring purse-seine fishery. There thus seems to be a close relationship between the distribution of herring on their feeding migration and *Calanus*. In early June, *C. finmarchicus* is usually more abundant in the coastal waters north and east of Iceland than in the East Icelandic Current proper. In the coastal waters the *Calanus* population is dominated by young copepodites (stages I—III) of the spring generation. As mentioned above during the present surveys herring have been observed in the cold East Icelandic Current evidently feeding on the wintering stock of *C. finmarchicus*. In 1964 the spawning of *C. finmarchicus* occurrend somewhat earlier than in 1963 and already in the first week of June herring were recorded in the coastal waters off Seydisfjord on the east

coast of Iceland, where young copepodites (stages I—III) of *C. finmarchicus* predominated. The coastal waters may nevertheless have provided better feeding conditions for the herring then the offshore waters where the wintering generation of *C. finmarchicus* was dying off after spawning. During the years 1961—1963 the difference in spawning time of the *C. finmarchicus* populations in the coastal and offshore waters may have been greater than in 1964. Until the spring generation of *C. finmarchicus* in coastal waters had developed to copepodite stages III—V, the herring have been mostly feeding on the wintering generation in the East Icelandic Current. Thus the migration of the herring into the coastal waters north and east of Iceland will depend on the time of spawning of *C. finmarchicus* in the different water masses as well as the density of the different copepodite stages.

During the years covered in these investigations the mature part of the Norwegian spring spawning stock has been dominated by the rich 1950 year-class. Until the 1959 year-class began to recruit the adult stock in 1964 recruitment was insignificant. It should be stressed therefore that in years with change in age composition the migration pattern of the herring may show considerably changes. The change in age composition observed in 1964 may therefore also have altered the migration pattern, when early in June herring were recorded in Icelandic coastal waters. It is known that in the summer the younger age groups of the Norwegian spring spawning stock usually have a more easterly distribution than the older ones (Fridriksson 1944, Pavshtiks 1956) and in 1964 the herring were mainly located east of Iceland. Also the shift in spawning time and place of the herring as observed on the Norwegian west coast (Devold 1963) may have to be taken into account when studying the feeding migration of the herring.

The data indicate that the time of the migration of the Norwegian herring to Icelandic waters as well as the migration routes are closely related to the biological seasons. Biological seasons are again associated with the hydrographical conditions and this may explain the apparent correlation between temperature and herring distribution observed several times also during the feeding seasons.

So far the present material is representative of "normal" years, it seems that the first invasion of Norwegian herring to Icelandic waters generally takes place in the first half of June. The herring pass through the East Icelandic Current east of Langanes in waters below 3°C. The shoals on migration are usually found in the cold waters near the strong temperature front north east of Iceland, feeding on the wintering stock of *C. finmarchicus* and other cold water forms such as *C. hyperborus*, *Themisto* and *Euphauciacea*.

It is tentatively concluded that the migration of the herring into the coastal waters, north and east of Iceland depends on the spawning time of *C. finmarchicus* in the different water masses as well as its density.

SUMMARY

The present material on zooplankton, temperature and herring have been collected in the Norwegian Sea, from the Faroes along the east and north-east coast of Iceland to Jan Mayen as a part of the Norwegian herring investigations, in collaboration with Iceland and U.S.S.R. during May and June 1961—1964.

Zooplankton was collected in vertical hauls from 50 m to the surface with a Juday net (1961—62) and a Hensen net (1963—64). Temperature was measured at standard depths from surface to 500 m. A termograph measured the surface temperature (at 4 m) throughout the cruises. Herring were located by horizontal and vertical accoustic fish detection devices (sonar, echo sounders).

The herring have been observed migrating across the East Icelandic Current east or north-east of Langanes in waters below 3°C. The distribution and migrations of herring in relation to temperature, plankton biomass (ml/m^3) and the distribution of the copepodite stages of *Calanus finmarchicus* are discussed.

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ON THE POSSIBILITY OF ESTIMATING YEAR-CLASS STRENGTH BY MEASURING ECHO-ABUNDANCE OF 0-GROUP FISH

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INTRODUCTION

The most commonly used method of estimating relative year-class strength in marine fishes is that of comparing the frequency distribution of the different year-classes in the exploited stocks. For a number of reasons it would be very desireable to determine the year-class strength at an earlier stage, and the first question that arises in this connection is then: at what stage or age in the life history of a fish is the strength of a year-class decided?

It is generally accepted that the natural mortality may be extremely high in the very early stages of life, but little is known about the magnitude of the early mortality rate, its variability, and the exact time of leveling off. Various authors have suggested that critical periods exist during early life when mass mortality may occur. Rollefsen (1930) suggests that in the case of the Arctic cod mechanical damage of eggs by wave action may have a serious effect. Hjort (1914, 1926) mentions mass mortality caused by lack of suitable food immediately after the time of yolk absorption and/or drift of larvae to unfavourable localities.

The hypothesis of critical periods has been discussed by Marr (1956), who concluded that although catastrophic mortalities, restricted in time, will always remain as a possibility, evidence points towards survival at a constant rate or at a constantly increasing rate, rather than towards the existence of critical periods.

In the case of post-larval fish fry, however, a number of workers have presented evidence of a proportional relationship between the abundance of 0-group fish of a particular year-class and the subsequent abundance of the same year-class at older ages (Russel 1935, Knudsen 1954, Saville 1956), and as a working hypothesis for the present investigation it is assumed that such a relation does exist.

During late summer and autumn, fish fry of many species occur

pelagically off the Norwegian coast and in the Barents Sea, and their distribution and abundance may be estimated by a combination of echo surveying and fishing experiments with pelagic trawl and purse seine.

The success of such investigations depends on the fulfilment of the following requirements:

1. a fairly complete and accurate charting of the vertical and horizontal distribution of the sound scatterers (*echo-abundance*),
2. easy and reliable identification of the sound scatterers,
3. exact measurements of the echo signals received,
4. knowledge of the relationship between the amount of scatterers and the strength of the echo signals, and how this relationship is influenced by depth, species, size, density and behaviour of the fish.

SOUND SCATTERING BY 0-GROUP FISH AND THEIR IDENTIFICATION

Scattering layers have been detected by echo sounding over broad reaches of the oceans (Hersey and Moore 1948, Johnson 1948, Tucker 1951, Parrish and Craig 1951). Sometimes observations made by different investigators in the same part of the ocean did not conform, but later investigations showed that these discrepancies were mainly due to differences in echo sounding equipment, especially the operating frequency.

Hersey and Backus (1962) distinguished between "scattering groups" and "scattering layers", and by their definition the scattering groups are discontinuous in the horizontal plane with horizontal dimensions less than, or only a few times larger than their vertical extension. These aggregations are generally of high scattering cross-section and are usually attributed to schooling fishes.

Scatterers which are more or less continuously distributed in the horizontal plane, their horizontal extension being many times their vertical range, form scattering layers. Commonly these layers appear on the record of an echo sounder as a uniform band of numerous weak echo traces.

The question has often arisen if density discontinuities themselves may give echoes to be recorded as scattering layers. In the North Sea this problem was carefully investigated by Weston (1958), who demonstrated that the sharp density gradient, usually present at the level of a scattering layer, was not the scattering agent. There is little doubt that the scattering layers are of biological origin, and planktonic animals, including fish larvae, are regarded as the probable source of these layers.

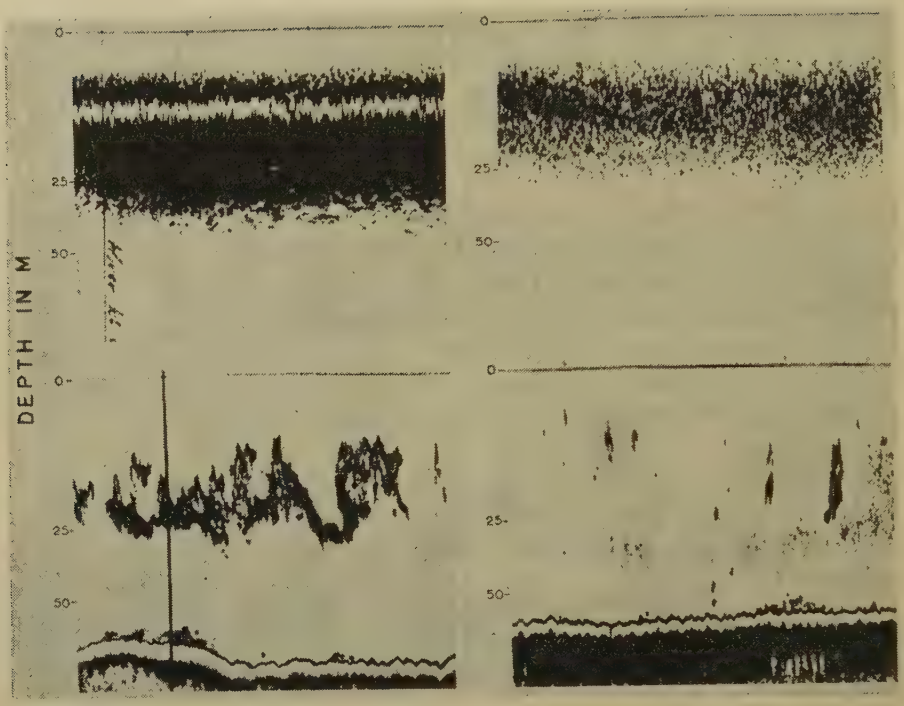

Fig. 1. Echo-recordings of sound scatterers identified as 0-group herring at night (above) and during daytime (below).

The sound scatterers referred to in the present paper are generally distributed in the top layers of water, comprising scattering layers as well as scattering groups according to the terminology of HERSEY and BACKUS. The vertical extension may reach 50—100 m during daytime, but at night the scatterers usually come closer to the surface. They are then distributed in typical layers, whereas during the day they cluster together in schools (Fig. 1), i.e. scattering groups as defined by HERSEY and BACKUS.

During the nineteen fifties sound scatterers were frequently recorded in the top layers of water in the Barents Sea and some success was made in identifying their cause by U.W.-photography (MIDTTUN and SÆTERSDAL 1959). However, until 1959 no systematic routine programme of identification was developed. For the present investigation midwater trawls have been used and proven successful to obtain samples from the depth strata where recordings were made.

Several attempts have been made to correlate the vertical distribution of sound scatterers recorded with the vertical distribution of marine animals as determined by capture methods (CUSHING 1963). In many types of gear, however, and especially in towed gears (i.e. trawls, plankton

nets etc.), the catch composition is greatly affected by mesh selection and different ability of avoidance. Consequently, one cannot be certain that the catches obtained with such gears give representative samples of the organisms responsible for the observed scattering.

Various other approaches of identification have been tried, for example in Scotland with U.W.-photography technique (Craig and Priestly 1963). Further developments of this technique have been applied by Soviet investigators (Fedorov, Truskanov and Yudanov 1963) who recently reported successful attempts of combining results from U.W.-photography experiments with echo survey data for the purpose of estimating the abundance of adult Atlanto-Scandian herring. During the last few years U.W.-photography experiments have also been carried out at this laboratory, but as yet, the methods and equipment applied do not seem to be sufficiently well developed for routine use.

DISTRIBUTION OF LARVAE IN RELATION TO THE SYSTEM OF WATER CURRENTS

During the last decade herring in Norwegian waters have spawned from the end of February to the middle of March, and mass hatching of larvae has been completed approximately three weeks later. During the following weeks the distribution of the larvae is determined by the current running along the coast of western and northern Norway. During the period 1957 to 1964 the major spawning grounds of the herring were located between Møre and Lofoten.

In the northernmost part of this area the main spawning of the Arctic cod also takes place, but somewhat later than that of the herring (March to April). When the herring larvae pass the Lofoten area they are mixed with cod larvae, and further northwards the pattern of the drift is nearly the same for the two species.

In most years the main spawning of the Arctic haddock takes place south of the Lofoten area, probably south of 65°N (Sætersdal 1952), and the spawning period overlaps that of the cod. The haddock larvae are also distributed in the surface layers, and consequently have a drift pattern similar to that of the cod and herring (Wiborg 1960).

In the areas north of Lofoten, the Barents Sea and the eastern part of the Norwegian Sea, the distribution of the larvae is largely determined by the system of water currents (Fig. 2, modified from Tantsura 1959).

From the shelf off the Lofoten islands the larvae are transported northwards by the coastal current. Passing the banks off Troms, the drift

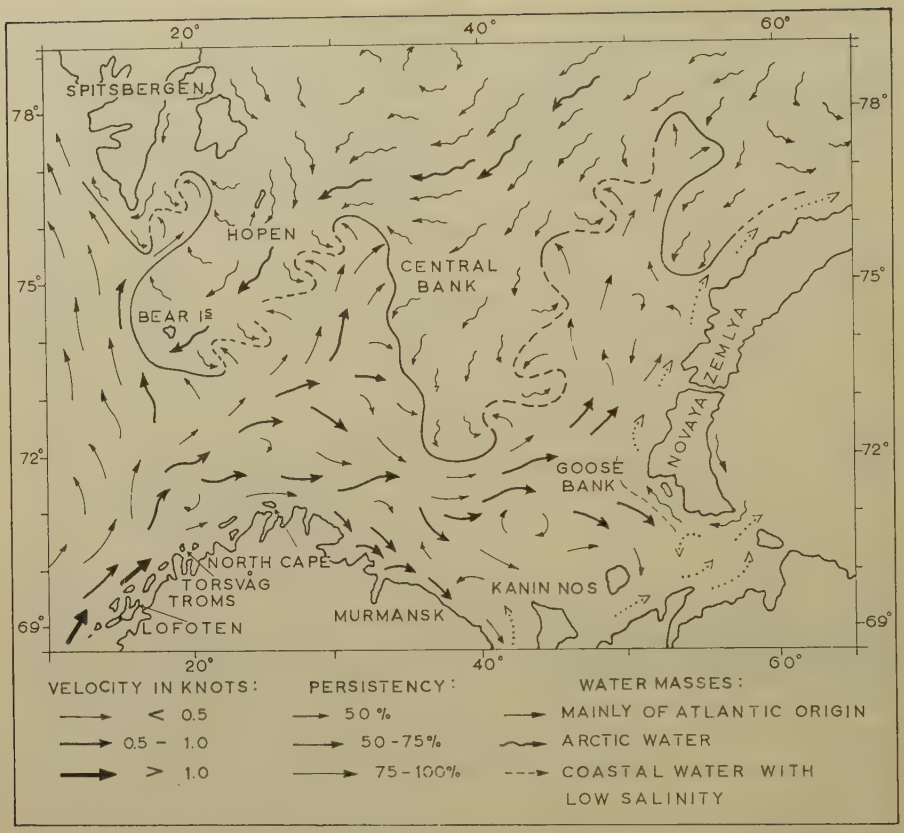

Fig. 2. The general current systems off northern Norway and in the Barents Sea (modified from TANTSURA 1959).

becomes more influenced by the Atlantic current, which in this area is intensively mixed with coastal waters (LJØEN 1962). Before reaching the entrance of the Barents Sea, the water masses split into several branches, one proceeding northwards, forming the Spitsbergen current. Off Torsvåg (70°30'N), where a large shelf is located, two east-going branches separate. One of these flows along the coast of West Finnmark (The North Cape Current), the other continues into the northern Barents Sea. The North Cape Current again splits into two branches, one along the southern and the northern slopes of the Goose Bank, the other passing near the Murman coast.

Considering this current system the most extreme distribution of larvae hatched during the same year, and being passively transported by currents, would be off the western shore of Spitsbergen (Hornsund Bank), the southwestern area of the Central Bank, the Novaya Zemlya

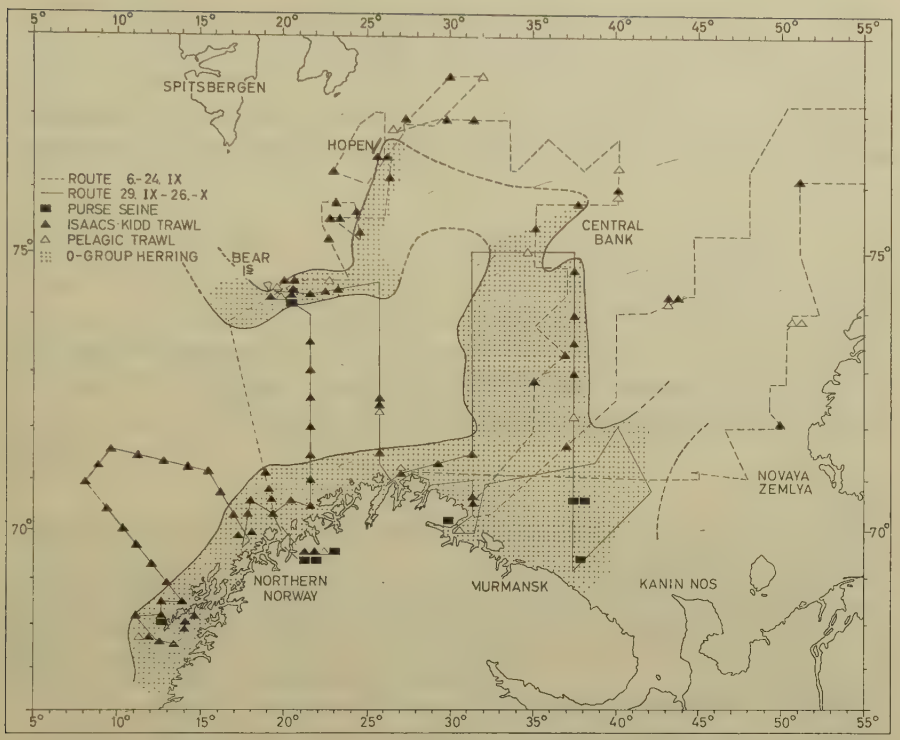

Fig. 3. The distribution of 0-group herring (mainly) in late September and October 1960.

shelf, the southern slope of the Goose Bank, Kanin Nos and the inlet of the White Sea.

This distribution is confirmed by the observations made during the last few years, which indicate that from August to October fish fry of various species are abundant in the surface layers off the coast of northern Norway and in the Barents Sea, (Dragesund and Hognestad 1959, 1962, Olsen 1960). At the end of the autumn the fry are concentrated along the frontiers between the cold and warm water masses covering the area from Spitsbergen to Bear Island and further to the east and south in the central and southeastern part of the Barents Sea (Fig. 3). A concentration also takes place along the coast, especially at the entrance of the fjords, whereas between the coast of northern Norway and Bear Island the larvae are less numerous. In late autumn the 0-group of cod, haddock, and to some extent also herring and capelin, descend and settle near bottom, and during the winter months fish fry are more rare in the surface layers.

THE RELATION BETWEEN ECHO SIGNALS AND SCATTERING AGENTS

The echo signal from an individual target in the receiver is transformed into an electric pulse of varying voltage (V_t), and the sum of voltages is given by:

$$V = \int_{t_1}^{t_2} V_t \, dt \qquad (1)$$

when the duration of the pulse is $t_2 - t_1$.
When a target passes through the beam of an echo sounder, echoes may be received for several successive transmissions, and the total sum of voltages of all signal pulses derived from the target is:

$$S_v = b\bar{V} \qquad (2)$$

where b is the number of individual echoes received, and $\bar{V}$ is the mean voltage of the pulses.

The strength and duration of the individual echoes are affected by the size of the target, and the maximum strength for fish of the same species is found to be a function of the size of the fish (MIDTTUN and HOFF 1961, RICHARDSON *et al.* 1959).

Scatterers distributed at a constant depth

The simple case is considered that fish of the same kind and size are sparsely and evenly distributed in a layer of constant depth, so that there is no overlapping of echoes from individual fish. Further, it is assumed that echoes from no other type of target are received.

When a ship with an echo sounder has covered a unit distance, one nautical mile, say, a number of n fish has passed through the beam, and the sum of voltages of all signals received is n times that received from one single fish. Thus, the sum of voltages received is directly proportional to the abundance of fish present.

When fish are more densely concentrated, echoes from two or more fish may be received at about the same time, i.e. their individual echoes overlap more or less completely and, eventually, when the density further increases a continuous layer or a school is formed.

A school or a layer will always have a vertical as well as a horizontal range, and the echo signals received are therefore produced both by direct reflections of the transmitted sound pulses and by reflections derived from multiple scattering of the sound. On the other hand the strength of the signal received from a school is also affected by interference, and by the fact that part of the transmitted sound energy is absorbed by the

school itself. CUSHING (in RICHARDSON *et al.* 1959) and MITSON and WOOD (1961) found that a square root relationship between catch per effort (square root of baskets/hr) and the amount of signals received existed under certain conditions; whereas SHISHKOVA (1963) found it necessary to add a term referring to the effects of multiple scattering, absorption etc.

The effect of variations in depth distribution

The absorption of sound energy by sea water is relatively low for medium and low frequencies, and within the limited depth range in question, i.e. usually less than 100 m, the effect of the sea water absorption may be completely neglected.

Because of the geometrical spread of the sound energy the signal voltage from an individual target is reduced proportionally to the square of the depth of the target:

$$V_d \propto d^{-2} \tag{3}$$

This reduction may conveniently be adjusted for in the receiver amplifier. Thus, if the amplifier is so arranged that the amplification, starting at a certain level when a sound pulse is transmitted, increases proportionally to the 2nd power of time, the signal voltage produced by the receiver is adjusted for the reduction with depth.

On the other hand the area covered by the beam increases with depth, and consequently also the number of reflecting targets when the target density is constant. Thus, the sum of signal voltages produced by a receiver in which the signals are amplified proportional to the 2nd power of time will tend to give an overestimate of the target density.

This is a particular problem when there is a considerable variation in depth distribution of scatterers. When the vertical range of distribution is small, but the mean depth of the scatterers varies with the locality (i.e. horizontally), this problem may be overcome by estimating the corresponding sum of signal voltages in a chosen standard depth. However, in the case of a large vertical range and/or considerable vertical density gradients, integration of signal voltages within several different depth intervals would become necessary.

INVESTIGATIONS IN THE BARENTS SEA FROM 17 AUGUST TO 6 OCTOBER 1963

In order to obtain a more precise and unbiased numerical estimate of the amount of echo signals received, an electronic echo-integrator was developed to work in conjunction with the research sonar equipment onboard the R/V "G. O. Sars". This instrument is summing all signal

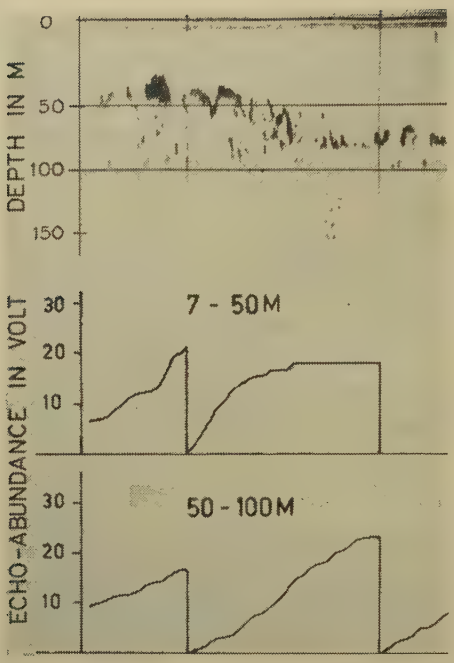

Fig. 4. Echo sounder recordings of a fish fry layer (top) and the corresponding echo abundance in volt from 7 to 50 m (middle) and 50 to 100 m (bottom) depth.

voltages generated by the echo sounder received within a set time interval (i.e. depth range). For each transmission any new signal voltages from the same depth range is added to the previous ones, and the result is displayed on a special paper recorder. A more detailed description of the echo-integrator is given in Appendix I. The integrator is reset to zero for each nautical mile sailed, and at present a duo-channel system is used. This allows integration over two different depth ranges at the same time, or over two different signal amplitude levels (Fig. 4).

This apparatus was first used during a cruise in the Barents Sea in August to October 1963, and its technical performance proved to be successful. Figures 5 and 6 show the areas covered and the grid of courses steered. On the charts are plotted the sum of signal voltages per five nautical miles, and iso-lines for equal leve ls of echo-abundance are drawn as adjusted to a standard cruising speed of 10 knots.

From 17 August to 11 September (Fig. 5) the main concentrations were found between latitudes 71°N and 75°N, longitudes 28°E and 33°E; whereas the survey from 15 September to 6 October indicated that a displacement towards the east had occurred, the main concentration being then between longitudes 33°E and 37°E.

Numerous fishing experiments with 10-foot Isaacs-Kidd midwater trawl (I.K.M.T.) and a pelagic trawl (P.T.) were carried out, and the catches obtained indicated that the sound scattering agents in these areas were mainly 0-group herring, cod and haddock mixed with some invertebrates (Appendix II). During the first survey (17 August to 11 September) a separate area of dense sound scatterers was located west of Novaya Zemlya (between longitudes 45°E and 51°E). These were indentified as being mainly fry of polar cod, capelin and various other cold water fish.

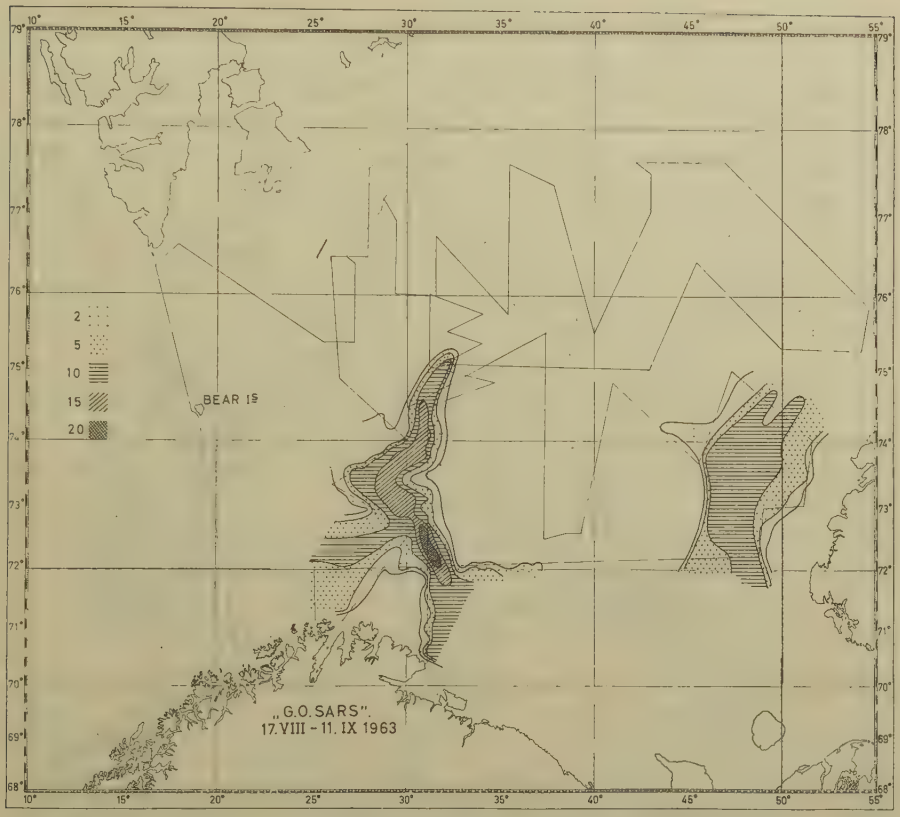

Fig. 5. Echo-abundance distribution as determined by the echo-integrator during the survey from 17 August to 11 September 1963. Equal levels of abundance are indicated by isolines.

When surveying the Bear Island area in August, the echo-integrator was not yet properly adjusted, and consequently integrator readings from this area are only available from the second survey. It is noted that during this second survey fairly high readings were obtained west of Bear Island, but unfortunately time did not permit an extension of the survey further to the north. However, considering the current system this concentration was probably the southernmost part of 0-group fish being transported northwards by the Spitsbergen current.

Along the Norwegian coast aggregations of sound scatterers, identified as 0-group herring were found at the entrance of the fjords, whereas on the banks off northern Norway (71°N to 72°N and 15°E to 25°E) sound scatterers were scarce. This distribution conforms with the observations made in previous years (see Fig. 3).

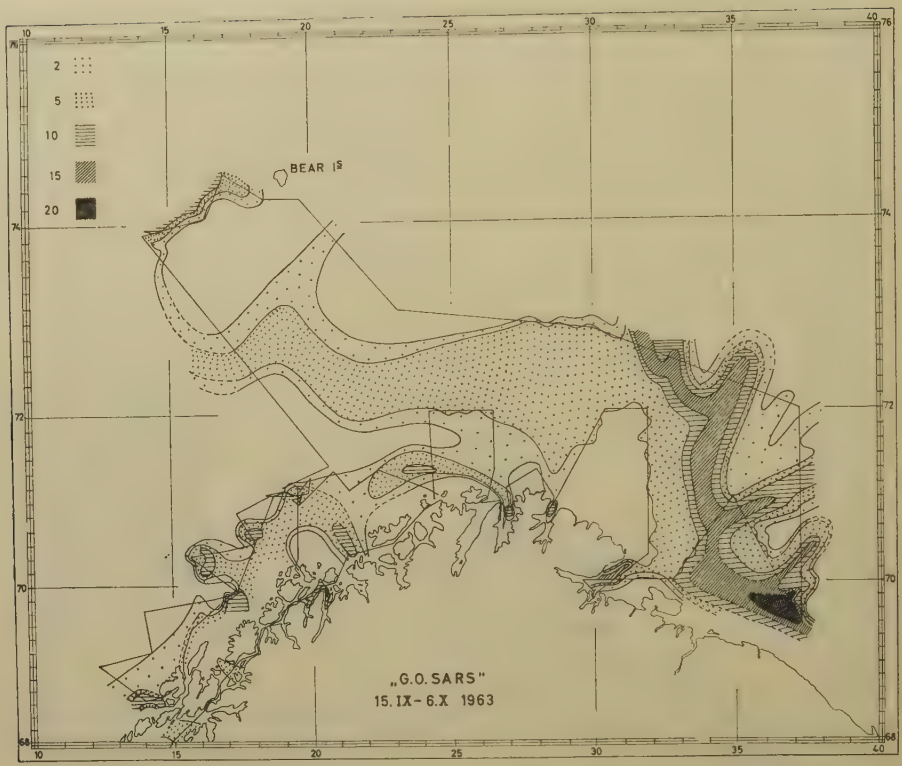

Fig. 6. Echo-abundance distribution as determined during the survey from 15. September to 6. October 1963.

During these surveys a pelagic trawl gave catches of fish fry and/or invertebrates whenever it was used at the exact depth where sound scatterers were recorded. This experience indicates that the pelagic trawl used is quite suitable for the purpose of identifying and sampling the sound scatterers, at least up to the size of 0-group fish. However, more experiments are needed in order to assess whether the catches taken with pelagic trawl are really representative with respect to species and size composition.

From Appendix II it appears that the cod predominated over haddock and herring in the central part of the Barents Sea, whereas along the Norwegian coast the herring were most abundant. The same was also the case west of Bear Island. In the area west of Novaya Zemlya the polar cod predominated over the capelin and the various other cold water species.

CONCLUDING REMARKS

Provided that the design and performance of the technical and electronic equipment are adequate, it might be assumed that precise measurements of the *echo-abundance* are feasible. The problem of charting the echo-abundance distribution in an area with sufficient accuracy is then mainly a matter of research vessel time.

To establish the biological significance or meaning of the echo-abundance, however, is a much more difficult problem. Ideally, the echo-abundance may be regarded as an index of total biomass of sound scattering agents in an area, but this index is affected by a large number of factors. Some of these are inherited with the equipment and methods used (i.e. frequency, power and technical quality, and performance of the equipment, operational skill, and how completely the area is surveyed), and may be accounted and adjusted for. Others are variable and to a large extent unknown. Thus, variations in size and species composition of the sound scatterers, and above all, their density and local distribution, will greatly affect the sum of signal voltages received.

Nevertheless, the problems encountered do not seem to be unsolvable. Identification is possible by fishing experiments with midwater gears (pelagic trawls, purse seine) and perhaps also with the aid of U.W.-photography and T.V.

Quantitative fishing is probably reliable only under certain conditions with a small meshed purse seine, but the samples taken with the more easily handled pelagic trawl, may give unbiased information regarding size and species composition. This question, however, needs further investigation.

Knowing the size and species composition and the target strength for each species, their relative contribution to the observed sound scattering, i.e. the echo-abundance, may be estimated. In this connection it should be noted that at present the target strength of the various kinds of fish fry and its variation with size are insufficiently known.

Remain then the effects of density variations etc. on the relation between the observed sound scattering and the abundance of scatterers. One approach is to develop theoretical models, the parameters of which may be determined experimentally. Such models would necessarily contain several variables, and be rather complex, especially in cases when various degrees of schooling occur. It is, therefore, suggested to avoid variability in schooling as far as possible by surveying areas abundant with fish fry during night time when the fish are more evenly distributed in continuous layers.

For this type of distribution, it is suggested to establish directly, by

Table 1. Comparison between purse seine catch and echo-abundance index.

Locality Position	Date Hour	Catch in numbers		Vertical range of echo trace in m	Echo-abundance index (30 kc/s)	
		Herring	Others		11–34 m	Total range
Ullsfjord N69°58′ E20°10′	27.9.63 1940—2100	600	—	10— 120	8.0	69.0
Ullsfjord N69°58′ E20°06′	28.9.63 0200—0300	500	9 1 of Scypho-medusae	10— 120	7.5	68.5
Ullsfjord N69°43′ E19°43′	30.9.63 1912—2000	8520	—	10— 80	35.5	128.8
Lyngenfjord N69°50′ E20°25′	1.10.63 0255—0400	5322	—	10— 60	26.0	—
Hadselfjord N68°28′ E14°30′	4.10.63 0213—0330	13424	—	10— 25	28.9	28.9

fishing experiments with purse seine, an empirical relationship between echo-abundance and fish fry present in an area. In September and October 1963 the first experiment for this purpose was made, the records of which are given in Table 1. When plotting the respective integrator readings against the square root of the numbers caught, five points are obtained which fit fairly well to a straight line. Thus, the observations made so far seem to indicate that this approach is feasible, and further experiments are planned.

SUMMARY

The possibility of estimating the distribution and abundance of 0-group fish by a combination of echo surveying and fishing experiments with pelagic trawl and purse seine is discussed.

The existence of scattering layers, their origin, and the identification of sound scatterers are discussed with special reference to observations made in recent years off northern Norway and in the Barents Sea. The scattering layers observed in late summer and autumn in this area consist mainly of 0-group fish of which herring, cod and haddock are most important.

The transport of the larvae from the spawning places in relation to the current systems is described. The observations indicate that during August to October fish fry are abundant in the surface layers of the north and

east going currents, and by the end of autumn the fry are aggregated along the frontiers between the cold and warm water masses covering the area from Spitsbergen to Bear Island and further to the east and south over the central and south-eastern parts of the Barents Sea.

The relation between echo signals received from scattering agents distributed at a constant depth and the amount of scatterers is discussed, as well as the effect of variations in depth distribution. Special attention is paid to the signal strength received from targets uniformly distributed in a layer or school of wide horizontal distribution.

The needs for theoretical as well as empirical studies of the relationship between the amount of echo signals received and the abundance of sound scatterers are stressed.

The first results of charting the echo-abundance distribution are presented. For this purpose an electronic echo-integrator was developed to measure exactly the signal voltages received.

Some preliminary data on the relationship between echo-abundance and the catch of fish fry with purse seine are also given.

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APPENDIX I

Short Description of the Echo-Integrator

The authors are greatly indebted to Mr. Ingvar Hoff, who has been responsible for the developement of the echo-integrator, and the description given below.

A block diagram of the complete installation is shown in Fig. 1, and the principle of operation is as follows:

The signals received during a predetermined time interval following each transmission of the echo-sounder (i.e. echoes from a certain depth range) are fed to an integrator unit (4) which accumulates the signal voltages received, and the output voltage of the integrator at any one moment is displayed by a separate paper recorder (5).

This is accomplished by feeding the signals through a gated amplifier (2), here called a signal selector, which is opened by a gate pulse produced by a pulse generator (9). The duration of this pulse, which may easily be varied, determines the time interval during which signals are fed to the integrator.

In the case that the integrator is not desired to start at the time of transmission (i.e. from the surface), the start of the pulse generator has to be delayed for a suitable period of time. This is arranged by a waveform generator (8), which provides a negative trigger pulse to the pulse generator.

At the moment the negative pulse has reached a certain level, the pulse generator starts and generates a gate pulse. This trigger level is selected in the pulse generator and enables regulation of the delay time between the moment the waveform generator is triggered and the moment the pulse generator excites the gate pulse.

Suppose that integration of the signal voltages between 75 and 150 m (t_2-t_1) is wanted and at the same time the sum of these voltages over one nautical mile should be added. At the moment the stylus of the echo-

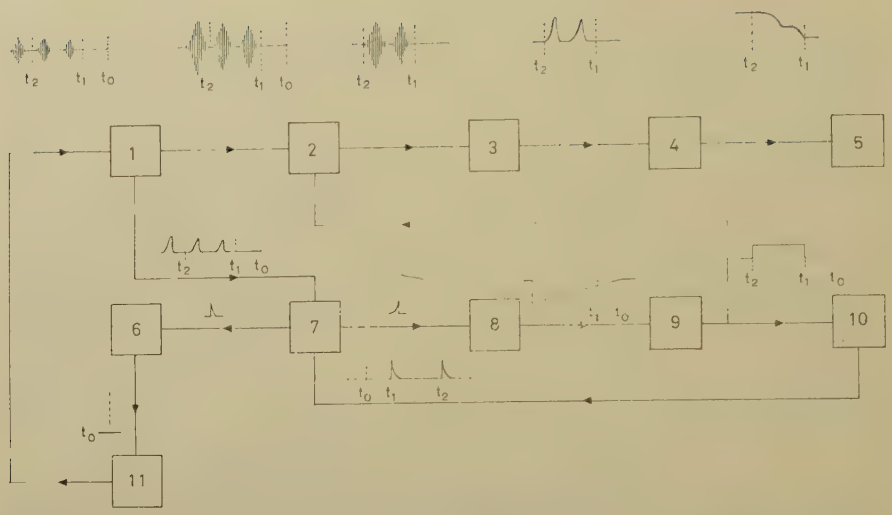

Fig. 1. Block diagram of the echo-integrator set-up:

1. Amplifier (Simrad)
2. Signal selector (gated amplifier)
3. Signal rectifier
4. Integrator (Tektronix, type 0)
5. Integrator recorder (Sanborn, type 322)
6. Transmitter (Simrad)
7. Echo-sounder recorder (Simrad)
8. Waveform generator (Tektronix, type 162)
9. Pulse generator (Tektronix, type 161)
10. Pulse deformer.
11. Transducer (Simrad).

sounder recorder passes the zero position (t_0) a contact in the recorder is closed and both the start pulse to the transmitter (6) and the start pulse to the waveform generator (8) are generated. After a certain time period, at the moment the stylus passes the 75 m position (t_1), the pulse generator starts, and provides a gate pulse to the signal selector (2). The signal selector which was blocked prior to the time t_1, will now feed signals from the echo-sounder amplifier (1) via a signal rectifier (3) to the integrator (4).

Again, after a certain time period, at the moment the stylus passes the 150 m position (t_2), the gate pulse ends, and the signal selector will remain blocked until the stylus passes the 75 m position after the next transmission.

The stylus of the integrator-recorder is attached to a galvanometer instrument, indicating at any one moment the output voltage (of the integrator).

This voltage will remain unchanged unless new signals are received, until it is reset to zero at the end of each nautical mile, through a relay, connected to the ship's log. The final value of the curveline at each reset provides then a measure of the amount of echo signals received.

In order to adjust the pulse generator easily and exactly to the desired

depth range, a part of the gate pulse is tapped and fed to a pulse deformer (10). This pulse deformer feeds two short positive pulses to the stylus of the echo-sounder recorder, the first pulse marking the beginning and the second the end of the gate pulse.

The various makes and types of units used are given in the text of the block diagram except for the signal selector, the signal rectifier and the pulse deformer which were specially designed for the purpose.

APPENDI

"G. O. Sars" 17 August to 4 October 1963. Rec

Note: Echo-abundance indices are for 38 kc/s visual cla

St. No. Position	Date Hour	Gear	Dist. towed	Catch in numbers			
				Her-ring	Cod	Had-dock	Other fish
49 N71°30′ E20°30′	17.8.63 1730	I.K.M.T.	1.5	—	—	2	—
50 N72°00′ E20°20′	17.8.63 2110	I.K.M.T.	1.0	—	6	—	—
51 N73°00′E19°52′	18.8.63 0320	I.K.M.T.	1.0	—	—	—	—
52 N73°30′ E19°37′	18.8.63 0650	I.K.M.T.	1.0	—	1	—	5 redfish 3 long rough d
54 N75°53′ E27°15′	20.8.63 0413	I.K.M.T.	1.2	—	—	—	4 long rough d 1 *Leptagonus decagonus*
55 N76°00′ E31°30′	21.8.63 0222	I.K.M.T.	1.2	—	—	—	—
57 N76°10′ E53°40′	24.8.63 0945	I.K.M.T.	0.8	—	—	—	7 polar cod 2 long rough d
58 N76°03′ E54°10′	24.8.63 1053	I.K.M.T.	—	—	—	—	ca. 100 polar
59 N75°18′ E52°20′	24.8.63 2007	I.K.M.T.	—	—	—	—	ca. 50 polar 1 sea scorpion
60 N75°05′ E32°27′	26.8.63 1845	I.K.M.T.	1.0	—	—	—	4 long rough d 1 sea scorpion
61 N75°09′ E32°25′	26.8.63 2050	P.T.	3.0	—	752	59	100 capelin
62 N74°31′ E31°46′	28.8.63 0722	P.T.	1.2	—	1	2	9 long rough d 3 *Liparis* sp. 2 *Lumpenus* sp. 1 *Leptagonus decagonus*
63 N74°16′ E31°13′	28.8.63 1230	I.K.M.T.	0.6	—	7	—	—
64 N74°05′ E31°13′	28.8.63 1339	P.T.	2.0	—	887	21	2 capelin
65 N73°00′ E31°13′	28.8.63 2205	I.K.M.T.	1.0	—	76	1	14 redfish

ishing experiments for identification of echo traces.
ions of the echograms, and for 30 kc/s integrator readings.

Evertebrates	No. of fish per n. mile	Echo-abund. index		Remarks
		38 kc/s	30 kc/s	
—	1.3	1	—	Integrator out of function
—	6.0	1	—	Integrator out of function
—	—	1	—	Integrator out of function
—	9.0	1	—	Integrator out of function
1 of euphausiids	4.2	0	—	Integrator out of function
specimens of diff. nedusae, 200 euphausiids, amphipods	—	0	7.4	
me *Clione*	11.3	1	—	
me amphipods	ca. 100	1	—	
—	ca. 50	1	—	
me *Clione*, ctenophores and amphipods	5.0	1	—	
ephalopods, some *Clione*, 1 scyhpomedusa	304.0	1	—	
me *Clione*, ctenophores	15.0	1	—	
—	11.7	2	—	
—	455.0	2	—	
—	91.0	2	—	

*.

APPENDIX

St. No. Position	Date Hour	Gear	Dist. towed	Catch in numbers			
				Herring	Cod	Haddock	Other fish
66 N72°04′ E31°13′	29.8.63 0636	I.K.M.T.	1.0	—	—	—	—
67 N70°49′ E31°13′	30.8.63 —	I.K.M.T.	1.1	15	51	2	—
68 N70°59′ E30°28′	30.8.63 0430	I.K.M.T.	0.7	—	1	—	—
70 N72°02′ E33°20′	3.9.63 0203	I.K.M.T.	1.0	—	3	—	—
71 N72°03′ E35°35′	3.9.63 0610	I.K.M.T.	1.0	—	—	—	—
72 N72°04′ E40°20′	3.9.63 1553	P.T.	2.1	—	—	—	712 polar cod
73 N72°05′ E46°40′	4.9.63 0406	I.K.M.T.	1.0	—	—	—	7 capelin 5 long rough da 3 *Lumpenus* sp. 1 *Liparis* sp.
74 N72°05′ E47°25′	4.9.63 0610	I.K.M.T.	1.0	—	—	—	15 polar cod 3 long rough da 2 *Liparis* sp. 1 capelin
75 N72°05′ E48°50′	4.9.63 0900	I.K.M.T.	1.0	—	—	—	6 *Gymnocanthus tricuspis* 3 capelin 2 polar cod 2 *Lumpenus* sp. 1 *Liparis* sp.
76 N73°00′ E49°15′	4.9.63 1417	I.K.M.T.	0.8	—	—	—	12 polar cod 3 *Artediellus uncinatus europeus* 2 *Gymnocanthus tricuspis*
77 N73°00′ E51°20′	4.9.63 1755	I.K.M.T.	1.0	3	—	—	3 *Gymnocanthus tricuspis* 2 *Artediellus uncinatus europeus*

ntinued)

Evertebrates	No. of fish per n. mile	Echo-abund. index		Remarks
		38 kc/s	30 kc/s	
—	—	1	48.8	Echo-trace at 100 m, trawl did not catch representatively
me euphausiids	61.8	2	9.4	
me Scyphomedusae	1.4	2	10.9	
me euphausiids	3.0	1	10.7	
—	—	0	—	
me euphausiids	339.0	0	—	
—	16.0	1	—	
me *Clione*	21.0	1	15.4	Integrator reading 5 n.m. before station
me *Clione*	14.0	2	—	Integrator out of function
me *Clione*	2.1	1	8.8	
me *Clione*	5.0	1	4.5	

St. No. Position	Date Hour	Gear	Dist. towed	Catch in numbers			
				Herring	Cod	Haddock	Other fish
78 N73°30′ E51°32′	4.9.63 2100	I.K.M.T.	1.0	—	—	—	15 polar cod 9 *Gymnocanthus tricuspis* 1 *Artediellus uncinatus europeus* 1 capelin 1 *Lumpenus* sp.
79 N74°20′ E50°15′	5.9.63 0325	I.K.M.T.	2.0	—	—	—	108 polar cod 6 *Artediellus uncinatus europeus* 2 *Gymnocanthus tricuspis*
80 N74°40′ E48°52′	5.9.63 0655	I.K.M.T.	0.5	—	—	—	52 polar cod
81 N74°08′ E46°20′	5.9.63 1515	I.K.M.T.	1.0	—	—	—	61 polar cod 1 *Artediellus uncinatus europeus*
82 N73°38′ E45°40′	5.9.63 1838	I.K.M.T.	0.7	—	—	—	46 polar cod 23 *Leptagonus decagonus* 1 long rough da
83 N73°38′ E45°40′	5.9.63 1904	I.K.M.T.	2.1	—	—	—	23 polar cod 12 *Leptagonus decagonus*
84 N74°46′ E41°05′	6.9.63 0525	I.K.M.T.	1.3	1	—	—	1 polar cod 1 *Leptagonus decagonus*
85 N74°38′ E37°20′	7.9.63 1445	P.T.	0.8		—	—	23 *Lumpenus* sp. 16 long rough da 1 polar cod 1 *Leptagonus decagonus* 1 *Artediellus uncinatus europeus* 1 *Anarhichas latifrons*

ntinued)

Evertebrates	No. of fish per n. mile	Echo-abund. index		Remarks
		38 kc/s	30 kc/s	
me Scyphomedusae	27.0	1	4.3	
me *Clione*	58.0	2	11.6	
me ctenophores and *Clione*	104.0	1	15.4	
me *Clione*	62.0	1	7.1	
me *Clione*	100.0	1	13.1	Trawl depth 43—44 m
me *Clione* and phausiids, *agitta* sp. tenophore	16.7	1	13.1	Trawl depth 55—65 m
me euphausiids and *Clione*	2.3	1	—	
me euphausiids and *Clione*	52.5	1	—	

St. No. Position	Date Hour	Gear	Dist. towed	Catch in numbers			
				Herring	Cod	Haddock	Other fish
86 N74°37′ E31°15′	8.9.63 0931	P.T.	3.0	—	720	7	3 *Leptagonus decagonus* 2 long rough d
87 N74°32′ E30°50′	8.9.63 1110	I.K.M.T.	1.3	—	—	—	—
88 N74°30′ E30°00′	8.9.63 1522	P.T.	1.9	—	1240	7	1 *Leptagonus decagonus* 1 long rough d
89 N74°53′ E26°30′	10.9.63 0914	I.K.M.T.	1.1	—	—	—	14 long rough d
90 N73°48′ E28°40′	10.9.63 2330	I.K.M.T.	1.0	18	33	—	—
91 N73°36′ E27°27′	11.9.63 0202	I.K.M.T.	1.0	8	11	—	—
92 N73°29′ E26°47′	11.9.63 0340	I.K.M.T.	0.6	—	—	—	—
93 N73°19′ E26°10′	11.9.63 0620	I.K.M.T.	1.0	—	—	—	—
94 N72°56′ E28°30′	11.9.63 1148	P.T.	2.8	—	1200	18	—
96 N71°50′ E28°20′	12.9.63 0003	I.K.M.T.	0.9	—	10	—	—
97 N71°20′ E24°16′	16.9.63 2223	I.K.M.T.	0.9	—	—	—	—
98 N72°00′ E24°12′	17.9.63 0324	I.K.M.T.	0.8	—	—	—	—
99 N71°56′ E26°34′	17.9.63 0930	P.T.	1.1	—	220	4	—
100 N70°51′ E27°02′	17.9.63 2230	I.K.M.T.	1.2	10	—	—	—
101 N70°51′ E27°02′	18.9.63 0150	I.K.M.T.	0.6	4	—	—	—
102 N70°51′ E27°02′	18.9.63 0217	I.K.M.T.	1.2	2	1	—	—
103 N70°53′ E28°35′	18.9.63 1145	P.T.	5.3	239	1	1	—
104 N71°40′ E29°55′	18.9.63 1940	I.K.M.T.	—	—	16	—	—

ntinued)

Evertebrates	No. of fish per n. mile	Echo-abund. index		Remarks
		38 kc/s	30 kc/s	
me *Clione*	244.0	1	44.	
—	—	1	21.0	Trawl did not catc h
—	657.4	1	29.6	
—	12.7	1	3.5	
euphausiids	51.0	1	16.3	
me euphausiids	19.0	1	10.7	
me Scyphomedusae	—	1	16.0	Trawl did not catch
me Scyphomedusae	—	2	3.6	
—	435.0	1	10.4	
—	11.1	1	7.9	
me euphausiids	—	1	8.8	
—	—	1	3.8	Trawl towed above top of echo-trace
Scyphomedusae	204.0	1	9.0	
me euphausiids and Scyphomedusae	8.3	2	—	Integrator out of function
me euphausiids and Scyphomedusae	6.7	2	—	Trawl towed at greater depth than previous haul
me euphausiids and Scyphomedusae	2.5	2	—	Trawl towed at greater depth than previous haul
few Scyphomedusae	45.5	1	2.0	
cephalopod	16.0	1	9.0	

APPENDIX

St. No. Position	Date Hour	Gear	Dist. towed	Catch in numbers			
				Herring	Cod	Haddock	Other fish
105 N70°02′ E30°39′	20.9.63 0438	P.T.	1.6	3564	175	78	8 blue whiting
106 N70°45′ E34°26′	20.9.63 1950	I.K.M.T.	0.5	3	36	—	—
107 N70°53′ E35°13′	20.9.63 2300	P.T.	2.0	76	800	3	4 blue whiting
108 N69°50′ E36°50′	21.9.63 0840	P.T.	1.5	—	196	3	—
109 N70°30′ E37°20′	21.9.63 1950	I.K.M.T.	0.6	1	12	—	—
111 N72°42′ E31°30′	23.9.63 0512	P.T.	1.7	—	—	3	—
112 N74°18′ E17°47′	24.9.63 1835	P.T.	1.0	126	4	—	A few long roug dab
113 N73°22′ E16°50′	24.9.63 2220	P.T.	1.0	—	20	7	1 *Triglops pingel*
116 N69°42′ E19°44′	30.9.63 2122	P.T.	1.0	240	12	11	—
117 N70°44′ E17°37′	2.10.63 1033	P.T.	1.5	—	—	—	—
118 N70°11′ E16°15′	2.10.63 1955	I.K.M.T.	2.0	1	—	—	69 *Myctophum glaciale* 1 blue whiting
119 N68°32′ E14°00′	3.10.63 1955	I.K.M.T.	2.6	1	1	—	—
120 N69°55′ E17°10′	4.10.63 1908	P.T.	2.1	448	—	—	—

ntinued)

Evertebrates	No. of fish per n. mile	Echo-abund. index		Remarks
		38 kc/s	30 kc/s	
ephalopods, some yphomedusae	2391.0	3	21.7	
cyphomedusa	78.0	1	—	Integrator out of function
—	442.0	1	14.8	
me Scyphomedusae	132.7	1	32.5	
—	21.7	2	15.8	
—	1.8	1	30.2	Trawl towed above most dense echo-trace
—	130.0	3	11.4	
me euphausiids	28.0	1	11.1	
itres of euphausiids, Scyphomedusae	263.0	2	14.4	
—	—	1	11.8	Likely trawl did not catch representativly
me euphausiids and Scyphomedusa cephalopod	35.5	0	16.3	
Scyphomedusa	0.8	1	4.5	
—	213.3	1	19.3	

ABUNDANCE ESTIMATES OF BARENTS SEA CAPELIN

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INTRODUCTION

The Barents Sea capelin is fished commercially during winter and spring when the mature stock enters coastal waters to spawn, and it is apparent from the history of the fisheries that great variations in spawning time and area have occurred and that the total abundance or stock strength has fluctuated widely. The impact of these fluctuations is strongly felt, not only in the fisheries for capelin itself, but since this little fish is a very important food organism for other fishes, changes in total abundance and distribution will have a marked effect on the fisheries for other species as well, notably on the fisheries for Arctic cod.

The Norwegian fisheries statistics contain data on capelin catch, number of vessels and duration of season, but it seems that the effects of changes in availability, weather conditions, market demands etc. are so great that catch per unit effort estimates are of rather doubtful value as realistic indices of stock abundance. Nevertheless, it is obvious from the output of the fisheries in recent years, and from research vessel observations, that the stock of capelin, which around 1960 seemed to be quite numerous, has since the season of 1961 declined greatly. The present paper describes an attempt to estimate the magnitude of this decline on the basis of the available data of age distribution on the mature stock.

Table 1. Percentage age distribution in the spawning stock of Barents sea capelin, 1959 to 1964.

Year	1959*		1960*		1961		1962		1963		1964	
Age \ Sex	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
2	1.8	2.6							0.2	0.1		0.3
3	67.0	70.4	33.1	49.5	1.2	4.7	2.0	8.4	2.3	7.7	1.9	6.5
4	31.2	27.0	66.1	50.0	94.2	94.5	63.9	66.9	93.5	91.1	47.2	58.0
5			0.8	0.5	4.6	0.8	33.9	24.4	4.0	1.1	50.9	35.2
6							0.2	0.2				

* Data from Prokhorov (1960)

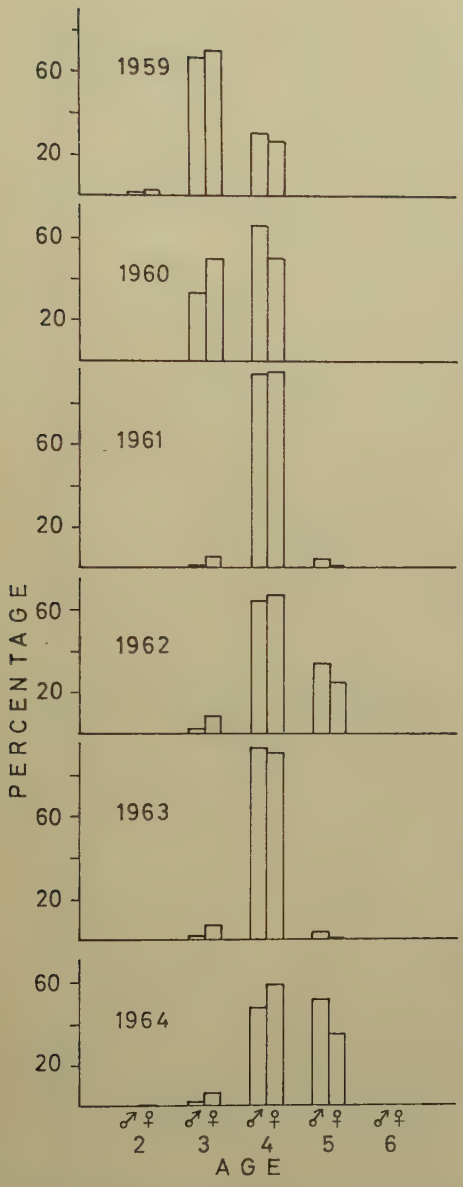

Fig. 1. Age distribution of the spawning stock of capelin, 1959 to 1964.

MATERIAL AND METHODS

Routine market and research vessel sampling of mature capelin has been carried out by the Institute of Marine Research each year since 1961, and combined with the data collected in 1959 and 1960 by the Polar Institute in Murmansk (Prokhorov 1960) they provide estimates of the age distribution of the spawning stock in six consecutive years, i. e. 1959 to 1964. (Table 1 and Fig. 1).

It is clear that the Barents Sea capelin spawn mainly when 3, 4 and 5 years old and the lack of older fish strongly supports the theory of a very heavy post-spawning mortality. Templeman (1948) and Prokhorov (1969) have reported observations suggesting that at least some capelin do survive to spavn for a second time, and similar observations of spent females maturing again, were made in August 1961 during a cruise with the R/V "G. O. Sars" to the Hopen Island banks. However, for the present purpose the small proportions of second time spawners may be disregarded, as well as the few 2 and 6 year-olds, which in so me years occur in the spawning stock. Accordingly:

$$p_3 + p_4 + p_5 = 1 \qquad (1)$$

when p_3, p_4 and p_5 denote the proportions spawning at age 3, 4, and 5 respectively, of the total number of a year-class (N) which survive until the age of maturity. These proportions may be different for the two sexes, and they may also vary from year-class to year-class.

For three consecutive year-classes there are the following relationships:

$$\frac{N_i \cdot {}_ip_4}{N_j \cdot {}_jp_3} = a \tag{2}$$

$$\frac{N_i \cdot {}_ip_5}{N_j \cdot {}_ip_4} = b \tag{3}$$

$$\frac{N_j \cdot {}_jp_4}{N_k \cdot {}_kp_3} = c \tag{4}$$

and

$$\frac{N_i \cdot {}_ip_5}{N_k \cdot {}_kp_4} = d \tag{5}$$

where the ratios a, b, c, and d are estimated from the percentage age distributions.

From these equations a formulae for N_j is established:

$$N_j = N_i \left(\frac{{}_ip_4}{a} + \frac{{}_ip_5}{b} + \frac{{}_ip_5 \cdot d}{bc} \cdot \frac{{}_kp_4}{{}_kp_3} \right) \tag{6}$$

Thus, if the parameters for the i-th year-class are known, N_j may be estimated, provided some measure of the ratio ${}_kp_4/{}_kp_3$ can be established. As a first approximation it is assumed that this does not differ much from that of the j-th year-class and hence:

$$\begin{aligned} N_j &\approx N_i \left(\frac{{}_ip_4}{a} + \frac{{}_ip_5}{b} + \frac{{}_ip_5 \cdot d}{bc} \cdot \frac{{}_jp_4}{{}_jp_3} \right) \\ &= N_i \left(\frac{{}_ip_4}{a} + \frac{{}_ip_5}{b} + \frac{ad\,({}_ip_5)^2}{b^2c \cdot {}_ip_4} \right) \end{aligned} \tag{7}$$

Dividing (3) with (2) gives:

$$\frac{{}_jp_3 \cdot {}_ip_5}{{}_jp_4 \cdot {}_ip_4} = \frac{b}{a} \tag{8}$$

and, similarly, from (4) and (5):

$$\frac{{}_kp_3 \cdot {}_jp_5}{{}_kp_4 \cdot {}_ip_4} = \frac{d}{c} \tag{9}$$

It is noticed that if there were no difference from year-class to year-class in the p-values these ratios would be identical. In this case the year-indices may be deleted and only one additional information is required to calculate p_3, p_4 and p_5.

If no additional information is available, alternative estimates may still be possible if the average age distribution can be assumed to indicate the right order of magnitude of the p-values.

In this case, by applying different values of, for example the ratio p_3/p_5, around that derived from the average age distribution, several series of estimates may be made.

In the present material of males ${}_{56}p_3 \cdot {}_{55}p_5/{}_{56}p_4 \cdot {}_{55}p_4 = 0.0257$ and ${}_{57}p_3 \cdot {}_{56}p_5/{}_{57}p_4 \cdot {}_{56}p_4 = 0.0244$. Such a close agreement would be expected if the p-values of these year-classes were nearly identical and it is reasonable to assume that this is in fact the case.

The average age distribution for the years during which these year-classes participated in the spawning, gives a value for the ratio p_3/p_5 of about 4, and hence, three series of estimates have been made applying values 3, 4 and 5 for the ratio p_3/p_5 of these year-classes. These have been used to estimate N_{55} and N_{57} relative to N_{56}, and to find the parameters for the subsequent year-classes by means of equation (7).

Contrary to that found for the males, in the material of females the ratio $p_3.p_5/p_4.p_4$ is not nearly constant for the first years of sampling. To follow the same procedure in the calculations as for the males one further assumption had therefore to be made, namely that the ratio p_3/p_4 is nearly the same for both the 1955 and the 1956 year-classes. Tables 2a and 2b give a record of the three series of parameters estimated for males and females separately, and in Table 3 are given the corresponding figures for the estimated relative abundance of the spawning stock.

DISCUSSION

The material on which these estimates are based are drawn from various sources and collected in different localities and at different periods of the spawning seasons. This might significantly bias the age distribution in the samples, particularly in the case of the females, since the younger females seem to be more abundant on the spawning grounds at the end of the season than the older ones. For the males, however, no change in age distribution during the season has been apparent, and the present data of the age distributions from 1959 to 1964 is probably more reliable for males than for females.

Nevertheless, it is noticed that the results obtained from both sets of data fluctuate in the same manner from year to year. In view of the fact that this good agreement is obtained from two quite independent sets of data, it would seem reasonable to conclude that the various assumptions

Table 2a. Males. Estimates of the parameters p_3, p_4, p_5 and N. applying different values for the ratio ${}_{55}p_3/{}_{55}p_5$ and taking N_{56} as unity.

Yearclass	A				B				C			
	${}_{55}p_3/{}_{55}p_5=3$				${}_{55}p_3/{}_{55}p_5=4$				${}_{55}p_3/{}_{55}p_5=5$			
	p_3	p_4	p_5	N	p_3	p_4	p_5	N	p_3	p_4	p_5	N
1955	0.203	0.730	0.068	0.131	0.226	0.717	0.057	0.151	0.248	0.702	0.050	0.168
1956	0.203	0.730	0.068	1.000	0.226	0.717	0.057	1.000	0.248	0.702	0.050	1.000
1957	0.203	0.730	0.068	1.821	0.226	0.717	0.057	1.601	0.248	0.702	0.050	1.436
1958	0.066	0.917	0.017	0.255	0.078	0.908	0.014	0.188	0.085	0.902	0.013	0.150
1959	0.050	0.694	0.255	0.145	0.061	0.716	0.223	0.088	0.069	0.727	0.203	0.061
1960	(0.050)	(0.694)	(0.255)	(0.050)	(0.061)	(0.716)	(0.223)	(0.020)	(0.069)	(0.727)	(0.203)	0.016

Table 2b. Females.

Yearclass	A				B				C			
	${}_{55}p_3/{}_{55}p_5=3$				${}_{55}p_3/{}_{55}p_5=4$				${}_{55}p_3/{}_{55}p_5=5$			
	p_3	p_4	p_5	N	p_3	p_4	p_5	N	p_3	p_4	p_5	N
1955	0.189	0.736	0.076	0.098	0.253	0.697	0.051	0.137	0.295	0.665	0.093	0.170
1956	0.198	0.777	0.026	1.000	0.260	0.732	0.107	0.100	0.306	0.681	0.031	1.000
1957	0.189	0.757	0.054	4.060	0.253	0.711	0.036	2.925	0.297	0.676	0.028	2.273
1958	0.200	0.796	0.005	0.765	0.260	0.736	0.003	0.384	0.301	0.697	0.002	0.254
1959	0.176	0.687	0.137	0.434	0.247	0.063	0.091	0.144	0.325	0.615	0.060	0.068
1960	(0.176)	(0.687)	(0.137)	(0.143)	0.247	(0.663)	(0.091)	0.033))	(0.325)	(0.615)	(0.060)	0.011

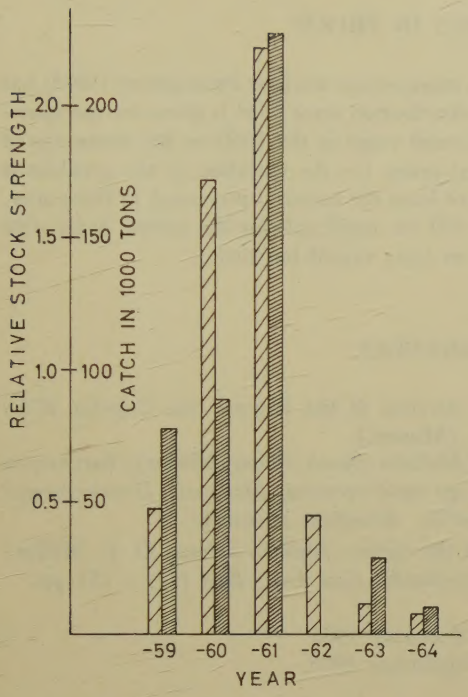

Fig. 2. Norwegian catch of capelin (right hand columns) in the years 1959 to 1964, and corresponding estimates of stock strength.

made in establishing the population model applied and in estimating the parameters are not quite unreasonable.

In Fig. 2 is shown the estimated relative strength of the mature stock of capelin in the years 1959 to 1964. These are the means of the estimates for males and females from series B in Table 3, added with provisional estimate of 1964. For comparison the Norwegian catch of capelin in the corresponding years is illustrated on the same figure. Except for the year 1962, when the capelin did not appear at the Norwegian coast at all, the trend in stock strength estimates is very similar to that of the yield of the fishery. This tend to indicate that in those years when the capelin are available to the Norwegian fishermen, the magnitude of the catch is largely governed by the size of the stock.

Table 3. Estimates of relative abundance of the spawning stock of Barents Sea Capelin 1959 to 1963.

Year	Males			Females		
	A	B	C	A	B	C
1959	.454	.560	.664	.218	.400	.564
1960	1.658	1.826	1.930	1.257	1.624	1.833
1961	2.144	2.046	1.937	2.631	2.387	2.187
1962	.551	.448	.384	.630	.472	.353
1963	.163	.112	.085	.285	.117	.063

NOTE ADDED IN PROOF

Since the manuscript was prepared a more recent work by PROKHOROV (1965) has been published, in which the yearly age distribution since 1954 is given for the spawning stock of capelin. For a period of several years in the 1950-ies the mean age of spawning was much lower than in recent years, i.e. the variation in the p-values is in fact much greater than what is apparent from the material presented in this paper. However, the method described would still be applicable for the period dealt with during which the age of maturity seems to have varied but little.

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